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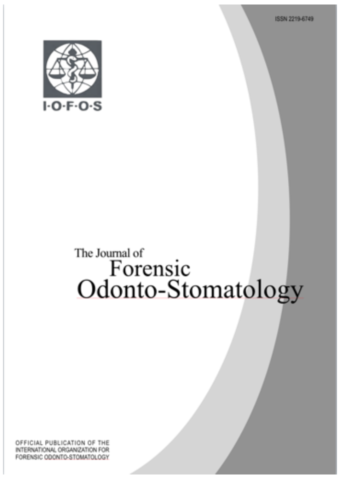

THE JOURNAL OF FORENSIC ODONTO-STOMATOLOGY

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Accuracy of two dental age estimation methods in the Indian population – A meta-analysis of published studies

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KEYWORDS

Demirjian;
Willems;
age estimation;
forensic odontology;
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ABSTRACT

Background: Dental age estimation using radiographic methods have gained considerable attention in the recent past. Although several such methods exist, Demirjian's method and Willems' method are very popular and have been used extensively. Whether these methods are applicable to the Indian population is not known.

Methods: A search of Pubmed, Embase and Google Scholar search engines was done using specific keywords to identify studies using Demirjian's and Willems' methods in the Indian population. Studies published up to July 2018 were considered, and after thorough review, 20 eligible studies were identified. Meta-analysis of data obtained from these articles was conducted on 3668 children for Demirjian's method and 3144 children for Willems' method. The weighted mean differences for both of these methods at 95% confidence intervals were assessed to identify the accuracy of each method in predicting the chronological age.

Results: Demirjian's method was found to consistently overestimate the age in Indian population, irrespective of the gender. The overestimation was in the order of few months. Willems' method resulted in underestimation of the age, although this was comparatively minimal in the order of 30 to 40 days.

Conclusion: Willems' method produced more accurate age which was very close to the chronological age, both in boys and girls. In contrast, Demirjian's method suffered from marked overestimation. Willems' method appears to be more suited to use in the Indian population.

INTRODUCTION

Age estimation in forensic odontology has received considerable attention in the last few decades. Various age estimation methods have been proposed in the past, although only a few of these have gained widespread acceptance. A wide range of criteria have been used for dental age estimation. Some rely on histological characteristics in the teeth, while many others rely on information obtained through radiographs. The radiographic methods have a distinct advantage since the technique is less invasive and can readily be used in live or dead subjects. Radiographic methods of dental age estimation include Demirjian's method, Nolla's method, Willems' method, Kvaal's method, etc.[1] However, most of these methods rely on the degree of mineralization of the developing teeth, and accurate age estimation up to only around 21 years of age (the

age at which most 3rd molars completely mineralize) is possible. Considering that forensic age estimation is mostly used for determining the age of minors for legal purposes, these radiographic methods are still very relevant in spite of this apparent limitation.
Among the various methods of radiographic dental age estimation, Demirjian's method[2] and Willems' method[3] are more commonly used. A quick literature search will reveal numerous studies using either of these two methods. However, many such studies have noticed that these age estimation methods are not applicable worldwide and need further adjusting to suit the population under investigation.[4] Population specific standards are therefore important. Since the original Demirjian's method and Willems' method were introduced based on French-Canadian and Belgian study populations respectively, their applicability to the Indian population needs to be verified. Various studies from different parts of India have been reported using these two age estimation methods in the past. Therefore, a systematic collection of studies published from India that used either or both of these age estimation methods was conducted, followed by a meta-analysis of the data.

METHODOLOGY

Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines were followed.[5] A research question following the PICO framework was first prepared as follows: Is Demirjian method (intervention) more accurate in estimating the age (outcome) when compared with Willems method (comparison), in Indian children (population)? This systematic review is registered with PROSPERO International prospective register of systematic reviews with the registration number CRD42018110536. The protocol can be accessed here: http://www.crd.york.ac.uk/PROSPERO/display_record.php?ID=CRD42018110536
The literature search was performed using specific keywords (Demirjian, Willems, age estimation, children) in different combinations in Pubmed, Embase, Google Scholar, and Google search engine. The keywords were intentionally picked to be as inclusive as possible in order to ensure that no relevant study would be missed out. An example of a search strategy used in Pubmed database is as follows: *Demirjian[All Fields] OR Willems[All Fields] AND "age estimation"[All Fields]*. Websites of known forensic odontology journals were also visited and the archives searched using the same keywords. Cross references from the included studies were also searched. Only studies published in English language up to July 2018 were included.
Studies were included if they met the following criteria:

- Original research studies (cross-sectional or non-cross-sectional in design)
- Studies using either or both the original Demirjian's method (1973) or original Willems' method (2001)
- Study relevant to the research question
- Full reports only (abstracts or conference proceedings without full report were not included)
- Study participants only less than 18 years of age (those that included subjects beyond this age were also considered for inclusion only if they provided data according to different age groups)
- Study population belonging to India

Studies were excluded if:

- the population being studied did not belong to India
- the population being studied was medically compromised or with developmental anomalies
- modified Demirjian's or Willems' methods were used exclusively
- the data provided was insufficient to compute statistics [mean, standard deviation (SD) and sample size were not provided]
- the language of publication was other than English

Both reviewers (HP and NK) extracted essential data from all the 20 selected studies, independently, in a Microsoft Excel sheet. The data that were extracted included first author name, year of study, place of study, age estimation methods used, sample sizes, chronological age of the study population (mean and standard deviation), and dental age of the study population (mean and standard deviation). Wherever available, the dental and chronological ages were also recorded according to gender.
Based on the data tabulated from the selected studies, the following comparisons were done:

- Mean difference in dental age (DA) versus chronological age (CA) using Demirjian's method
- Mean difference in dental age (DA) versus chronological age (CA) using Willems' method

The quality of the included articles was assessed independently by another reviewer, using QUADAS-2 (Quality Assessment Tool for Diagnostic Accuracy Studies).[6] QUADAS-2 uses a set of questions divided under four domains (patient selection, index test, reference standard, and flow and timing) to assess the risk of bias and applicability of each included study. All included studies were found to have a low risk of bias.

STATISTICAL METHODS

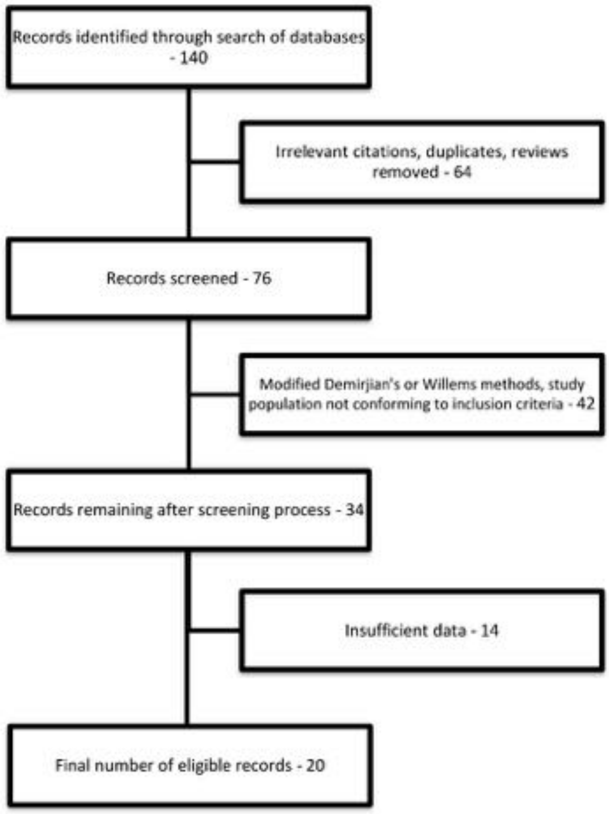
The above outcomes were assessed independently for the entire population, for boys and for girls. Mean difference (MD) with 95% confidence interval (CI) and p-values were calculated for the data extracted, using Cochrane RevMan v5.3 software. Tau and I^2 test were performed in all the datasets to evaluate the heterogeneity of the samples, based on which either a random effects model or a fixed effects model was used to compute the MD and CI. An I^2 value greater than 50% or a significant Tau value ($p < 0.05$) was considered suggestive of a heterogenous sample, and random effects analysis was used in such cases. For samples that were homogenous, a fixed effects model was used to determine the MD.

RESULTS

Our initial search resulted in the identification of 140 potentially valid citations. After duplicates were removed (n=64), we were left with 76 citations. Full texts of these 76 citations were accessed and both the reviewers (HP and NK) went through the methodology in each of them to assess their validity for inclusion in our study. This screening resulted in the exclusion of 42 records, since they used either revised Demirjian's or revised Willems' methods or because the study population was not from India. From the remaining 34 citations, another 14 had to be finally excluded because they did not provide enough data (mean, SD and sample size were not provided) for inclusion in the meta-analysis. The final number of eligible citations was 20 (Fig 1).[7-26]

Five[8,9,14,17,18] out of the 20 included studies had data for both Demirjian's method and Willems' method, nine[7,10-13,15,16,19,20] had data for Demirjian's method only, and six[21-26] had data for Willems' method only. Out of the 14 studies that had used Demirjian's method for age estimation, only 10 [7-11,13-15,17,19] had gender specific data. Similarly, out of the 11 studies with Willems method of age estimation, only 10[8,9,14,17,21-26] had gender specific data. A summary of important findings from the included studies is given in Table 1. Most studies reported that Demirjian's method significantly overestimated the age in their sample.

Figure 1. PRISMA flowchart



Meta-analysis was performed on the 20 included studies with the data extracted. Age estimation using original Demirjian's method was done in a total of 3668 children whose chronological age was between 4 and 18 years. Of these, gender specific data was available for 1722 boys and 1426 girls. The pooled sample size for age estimation using Willems method was 3144 children ranging from 5 to 17 years in chronological age. Gender specific data was available for 1617 boys and 1415 girls in this population. It was found that the data for Demirjian's age estimation were considerably heterogenous, so a random effects model was used to compute MD. Data for Willems age estimation were more homogenous, and hence a fixed effects model was used to compute MD for these values.

Table 1. Key findings of all included studies

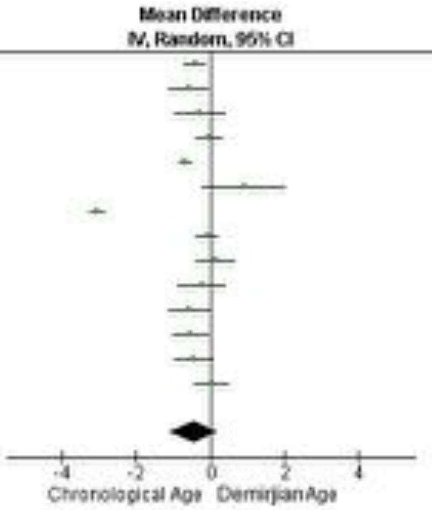
Study	Study population from	Age estimation methods used	Sample details			Age range	Key findings and conclusions
			Total	Male	Female		
Chandramohan 2018[7]	Karnataka	Demirjian's method	200	95	105	11 to 16	Significant overestimation by Demirjian's method was noticed in all age groups. A correction factor of +/- 0.5 was suggested.
Grover 2012[8]	Haryana	Demirjian's and Willems' methods	215	102	113	6 to 15	Both methods showed overestimation of age, but Willems' method was more accurate than Demirjian's method in both genders
Gupta 2015[9]	Haryana	Demirjian's and Willems' methods	70	37	33	9 to 16	Willems' method was better in estimating the age of Indian males. Demirjian's method was better for Indian females.
Hegde RJ 2015[10]	Maharashtra	Demirjian's method	197	115	82	6 to 12	Demirjian method produced overestimation of dental age by 2 days in boys and 37 days in girls.
Hegde S 2018[11]	Rajasthan	Demirjian's original and revised 7-tooth and 4-tooth methods	1200	699	501	5 to 15	All 4 methods produced overestimation. Revised 7-tooth method was most accurate of all.
Jayaraj 2017[12]	Karnataka	Demirjian's method	30	15	15	6 to 18	Demirjian's method was more accurate and consistent among the 6-18 year old children living in Mangalore district.
Koshy 1998[13]	Karnataka	Demirjian's method	184	93	91	5 to 15	Demirjiian's method was not applicable in South Indian children. Overestimation by 3.04 years in boys and 2.82 years in girls was determined.
Mohammed 2015[14]	Andhra Pradesh	Demirjian's, Willems', Nolla's and adopted Haavikko's methods	660	330	330	6 to 16	Demirjian's method overestimated age, while Willems' underestimated. All four methods were reliable in estimating age.
Nanda 2017[15]	Himachal Pradesh	Demirjian's method	100	49	51	9 to 14	There was good correlation between chronological age and dental age, especially in males.
Patel 2014[16]	Gujarat	Demirjian's method	170	85	85	4 to 16	Age estimation using Demirjian's method was found to be accurate for the population studied.
Patel 2015[17]	Gujarat	Demirjian's and Willems' methods	180	90	90	6 to 17	Willems' age estimation method proved to be more accurate and consistent than Demirjian's method.

Patnana 2014[18]	Andhra Pradesh	Demirjian's, Haavikko's and Willems' methods	102	NA	NA	6 to 14	Demirjian's method overestimated age, while Willems' underestimated. Dental age estimation by Willems' method found to be most accurate.
Pratyusha 2017[19]	Andhra Pradesh	Demirjian's, Cameriere's and modified Cameriere's methods	60	30	30	9 to 14	Chronological age was close to dental age in modified Cameriere's method.
Sinha 2014[20]	Uttar Pradesh	Demirjian's and Nolla's methods	300	150	150	6 to 15	Demirjian's method was applicable to all age groups in both genders with better accuracy than Nolla's method.
Hegde 2016[21]	Rajasthan	Willems' method (original and modified)	1200	699	501	5 to 15	Original Willems method was more accurate in estimating age of boys, while modified Willems was better in girls. Both methods were appropriate to use.
Kapoor 2017[22]	Himachal Pradesh	Willems' method	55	30	25	6 to 14	Willems method was more accurate than skeletal age estimation method. Willems method can be accurately applied to estimate chronological age.
Mohammed 2014[23]	Andhra Pradesh	Willems' method	332	166	166	6 to 16	Willems method underestimated age of males by 0.69 years and females by 0.08 years. Willems method can be used to generate dental age in individuals with unknown chronological age.
Priya 2015[24]	Tamil Nadu	Willems' method	60	30	30	13 to 15	Underestimation was observed when Willems method was used, both in males and females. Willems method may be suitable in the studied population.
Rajeev 2018[25]	Kerala	Willems' method	60	30	30	8 to 16	Significant correlation was noticed between dental age and chronological age. Willems method was better applied for males than females.
Sathawane 2017[26]	Chattisgarh	Demirjian's 8-tooth method and Willems' method	210	103	107	7 to 16	Overestimation by Willems method, and underestimation by Demirjian's 8-tooth method was observed. However, both methods showed close correlation with chronological age.

Meta-analysis of studies using Demirjian's method of age estimation

When the overall population of 3668 children was considered, it was observed that most of the studies showed an overestimation of age by Demirjian's method (Chronological age lesser than Dental age; CA-DA in negative values). The study by Jayaraj et al.[12] was significantly different in that it reported a marked underestimation of age by Demirjian's method. The overall weighted mean difference (WMD) was found to be -0.45 years, indicating that the Demirjian method overestimated the dental age by nearly 5.5 months as compared to the chronological age (Fig. 2).

Figure 2. Comparison of Demirjian's dental age with the chronological age of the entire population



Study or Subgroup	Chronological Mean	Chronological SD	Chronological Total	Demirjian Mean	Demirjian SD	Demirjian Total	Weight	Mean Difference IV, Random, 95% CI
Chandramohan 2018	13.8	1.45	200	14.24	1.5	200	7.4%	-0.44 [-0.73, -0.15]
Grover 2012	10.56	2.88	215	11.16	2.8	215	7.1%	-0.60 [-1.14, -0.06]
Gupta 2015	13.949	2.4	70	14.244	1.632	70	6.9%	-0.29 [-0.97, 0.38]
Hegde RJ 2015	8.731	1.82	197	8.771	1.82	197	7.3%	-0.04 [-0.40, 0.32]
Hegde S 2018	10.75	2.72	1200	11.44	0.08	1200	7.5%	-0.69 [-0.84, -0.54]
Jayaraj 2017	13.281	2.057	30	12.373	2.352	30	6.1%	0.91 [-0.21, 2.03]
Koshy 1998	9.899	0.295	184	12.976	1.308	184	7.4%	-3.08 [-3.27, -2.88]
Mohammed 2015	12.455	2.335	660	12.55	2.798	660	7.4%	-0.10 [-0.37, 0.18]
Nanda 2017	11.52	1.586	100	11.385	2.111	100	7.2%	0.13 [-0.38, 0.65]
Patel 2014	11.137	3.018	170	11.372	3.052	170	7.0%	-0.23 [-0.88, 0.41]
Patel 2016	11.239	2.939	180	11.812	2.647	180	7.1%	-0.57 [-1.15, 0.00]
Patnana 2014	12.27	1.67	102	12.81	1.81	102	7.2%	-0.54 [-1.02, -0.06]
Pratyusha 2017	11.4	1.1	60	11.85	1.73	60	7.2%	-0.45 [-0.97, 0.07]
Sinha 2014	10.94	2.88	300	10.92	2.84	300	7.2%	0.02 [-0.44, 0.48]
Total (95% CI)			**3668**			**3668**	**100.0%**	**-0.45 [-1.09, 0.20]**

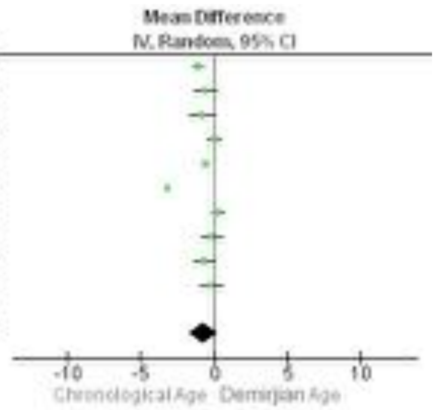
Heterogeneity: $Tau^2 = 1.45$; $Chi^2 = 609.42$, df = 13 ($P < 0.00001$); $I^2 = 98\%$

Test for overall effect: $Z = 1.36$ ($P = 0.17$)

In boys, it was found that the WMD was -0.74 years, suggesting that Demirjian's method overestimated dental age by almost 9 months in male children. With the exception of Mohammed et al.[14] and Hegde et al.[10], all the remaining studies individually reported similar overestimation by Demirjian's method (Fig. 3).

In girls, the difference between chronological age and Demirjian dental age was comparatively less than in boys. However, Demirjian's method still overestimated the dental age by almost 6 months in girl children (WMD = -0.51 years). Similar findings were noticed in the individual studies, although Gupta et al.[9], Nanda et al.[15] and Pratyusha et al.[19] reported either an underestimation or no difference in DA as compared to CA in female children (Fig. 4).

Figure 3. Comparison of Demirjian's dental age with chronological age in boys



Study or Subgroup	Chronological Age Mean	Chronological Age SD	Chronological Age Total	Demirjian Age Mean	Demirjian Age SD	Demirjian Age Total	Weight	Mean Difference IV, Random, 95% CI
Chandramohan 2018	13.8	1.34	95	14.9	1.54	95	10.2%	-1.10 [-1.51, -0.69]
Grover 2012	10.27	2.8	93	10.93	2.68	93	9.7%	-0.66 [-1.45, 0.13]
Gupta 2015	13.62	2.17	37	14.47	1.69	37	9.6%	-0.85 [-1.74, 0.04]
Hegde RJ 2015	8.973	1.87	115	8.969	1.892	115	10.1%	0.00 [-0.48, 0.49]
Hegde S 2018	10.81	2.6	699	11.44	0.11	699	10.4%	-0.63 [-0.82, -0.44]
Koshy 1998	9.89	0.31	184	13.1	1.23	184	10.4%	-3.21 [-3.39, -3.03]
Mohammed 2015	12.53	2.4	330	12.29	2.92	330	10.2%	0.24 [-0.17, 0.65]
Nanda 2017	11.41	1.526	49	11.575	2.009	49	9.9%	-0.16 [-0.87, 0.54]
Patel 2016	10.936	2.802	90	11.623	2.409	90	9.8%	-0.69 [-1.45, 0.08]
Pratyusha 2017	11.45	1.2	30	11.68	1.79	30	9.8%	-0.23 [-1.00, 0.54]
Total (95% CI)			1722			1722	100.0%	-0.74 [-1.71, 0.24]

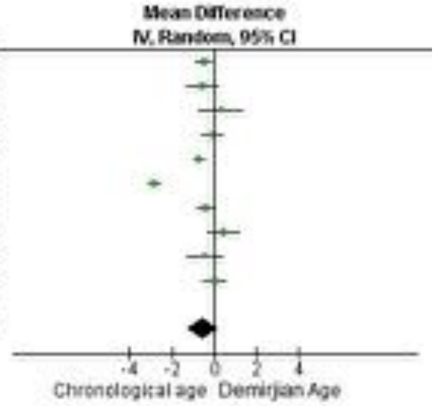
Heterogeneity: $Tau^2 = 2.38$; $Chi^2 = 557.79$, df = 9 ($P < 0.00001$); $I^2 = 98\%$

Test for overall effect: $Z = 1.48$ ($P = 0.14$)

Figure 4. Comparison of Demirjian's dental age with chronological age in girls

Study or Subgroup	Chronological Age Mean	SD	Total	Demirjian Age Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI
Chandramohan 2018	13.8	1.55	105	14.29	1.46	105	10.4%	-0.49 [-0.90, -0.08]
Grover 2012	10.81	2.94	113	11.37	2.9	113	9.6%	-0.56 [-1.32, 0.20]
Gupta 2015	14.31	2.62	33	13.99	1.55	33	8.8%	0.32 [-0.72, 1.36]
Hegde RJ 2015	8.391	1.705	82	8.491	1.686	82	10.2%	-0.10 [-0.62, 0.42]
Hegde S 2018	10.68	2.87	501	11.42	0.14	501	10.6%	-0.74 [-0.99, -0.49]
Koshy 1998	9.91	0.28	91	12.75	1.38	91	10.6%	-2.84 [-3.13, -2.55]
Mohammed 2015	12.38	2.27	330	12.81	2.65	330	10.5%	-0.43 [-0.81, -0.05]
Nanda 2017	11.63	1.654	51	11.188	2.216	51	9.6%	0.44 [-0.32, 1.20]
Patel 2016	11.541	3.055	90	12.001	2.867	90	9.3%	-0.46 [-1.33, 0.41]
Pratyusha 2017	11.34	1.01	30	11.34	1.01	30	10.2%	0.00 [-0.51, 0.51]
Total (95% CI)			**1426**			**1426**	**100.0%**	**-0.51 [-1.23, 0.21]**

Heterogeneity: Tau² = 1.25; Chi² = 223.24, df = 9 (P < 0.00001); I² = 96%
Test for overall effect: Z = 1.39 (P = 0.16)



Meta-analysis of studies using Willems method of age estimation

The overall sample size for Willems method of age estimation was 3144 children.

We found that among the 11 studies that had included Willems age estimation method, six reported overestimation, while the other five reported underestimation of dental age. The weighted mean difference determined using statistical methods was +0.09 years, indicating that Willems method underestimated the dental age by about 1 month (Fig. 5).

When boys were considered alone, the WMD was +0.11 years, which suggests that there was an underestimation by about 40 days using Willems method. Most of the studies included in the meta-analysis had similar findings of marginal underestimation or no difference in Willems DA as compared to CA, except Mohammed et al.,[14,23] who reported a marked underestimation in both of their studies (Fig. 6).

Among girls, the WMD was almost 0, which suggested that Willems DA was as close as possible to CA. Although some of the included studies showed a much higher variation in Willems DA, these studies had small sample sizes and carried less weightage when the WMD was calculated for the entire population (Fig. 7).

A summary of the findings of our meta-analysis is given in Table 2.

Figure 5. Comparison of Willems dental age with chronological age in the entire population

Study or Subgroup	Chronological Age Mean	SD	Total	Willems Age Mean	SD	Total	Weight	Mean Difference IV, Fixed, 95% CI
Grover 2012	10.86	2.8	215	10.56	2.88	215	5.2%	0.30 [-0.24, 0.84]
Gupta 2015	13.945	2.4	70	13.992	1.76	70	3.1%	-0.05 [-0.74, 0.65]
Hegde 2017	10.75	2.72	1200	10.84	2.83	1200	30.4%	-0.09 [-0.31, 0.13]
Kapoor 2017	9.89	1.46	55	9.96	1.46	55	5.0%	-0.07 [-0.62, 0.48]
Mohammed 2014	11.92	2.63	332	11.53	2.91	332	8.4%	0.39 [-0.03, 0.81]
Mohammed 2015	12.455	2.335	660	12.055	2.736	660	19.9%	0.40 [0.13, 0.67]
Patel 2016	11.239	2.939	180	11.296	2.749	180	4.3%	-0.06 [-0.64, 0.53]
Patnana 2014	12.27	1.67	102	12.06	1.8	102	6.6%	0.21 [-0.27, 0.69]
Priya 2015	13.82	0.805	60	14.08	1.506	60	8.0%	-0.26 [-0.69, 0.17]
Rajeev 2018	11.7	2.2	60	11.2	1.8	60	2.9%	0.50 [-0.22, 1.22]
Sathawane 2017	11.83	2.464	210	11.963	2.717	210	6.1%	-0.13 [-0.63, 0.36]
Total (95% CI)			**3144**			**3144**	**100.0%**	**0.09 [-0.03, 0.22]**

Heterogeneity: Chi² = 15.46, df = 10 (P = 0.12); I² = 35%
Test for overall effect: Z = 1.48 (P = 0.14)

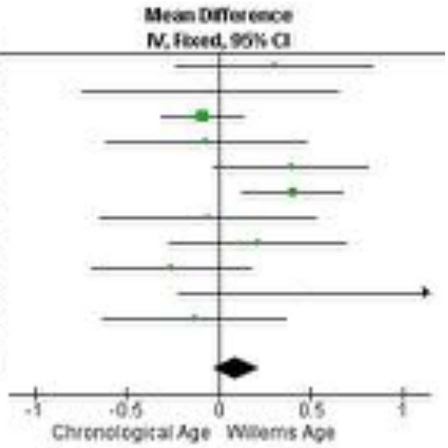


Figure 6. Comparison of Willems dental age with chronological age in boys

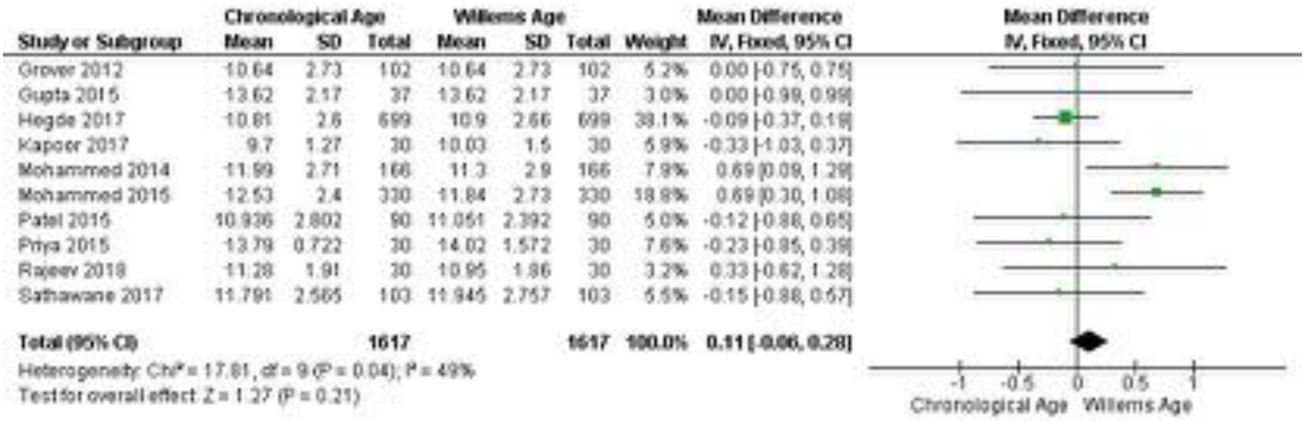


Figure 7. Comparison of Willems dental age with chronological age in girls

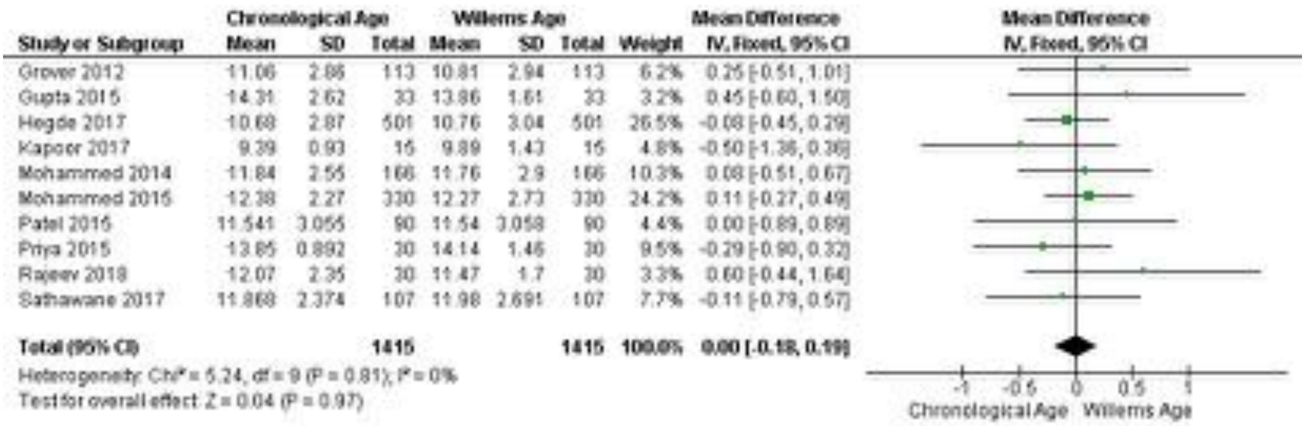


Table 2. Summary of key findings of our meta-analysis

Population	Demirjian	Willems
Boys	Overestimation (0.74 years)	Underestimation (0.11 years)
Girls	Overestimation (0.51 years)	Negligible difference
Overall	Overestimation (0.45 years)	Underestimation (0.09 years)

DISCUSSION

Growth is an important indicator of the health and nutritional status of an individual, particularly a child. The physiological age, therefore, is deemed to be more important than the chronological age of an individual. The concept of physiological age is based on the degree of maturation of various tissue systems.[2] Although many methods of physiological age determination exist, skeletal age has been used ubiquitously for several decades. Different skeletal age estimation methods include the Greulich-Pyle (GP) Atlas method, the Tanner Whitehouse 2 (TW2) method and the Gilsanz-Ratibin (GR) Atlas method.[27] However, it has been recognized that skeletal maturation is far more influenced by external environmental factors and hormonal influences than dental maturation is. Therefore, interest in dental age estimation as a reliable method has been on the rise in the past few decades.

Dental development and maturation, like skeletal development and maturation, shows variations between populations. Some of the commonly used dental age estimation methods have been proposed on the basis of standardizations derived from non-Indian population data. It is therefore questionable whether these methods hold good for the Indian population. Hence, we performed a systematic review and meta-analysis of all published data that used two popular dental age estimation methods (Demirjian's method and Willems' method) in the Indian population.

The findings of our review suggest that the original Willems' method gave dental ages that were very close to the chronological ages of the subjects. Although Willems method underestimated the age, especially in boys, this underestimation was marginal. In contrast, the original Demirjian's method produced a significant overestimation in the Indian population. It is our opinion that the original Willems method may be used for age estimation for forensic or anthropological purposes in the Indian population, if the levels of accuracy reported here are acceptable.

Both Demirjian's and Willems' methods have been revised in the past to improve accuracy of age estimation. The original Demirjian's method uses seven mandibular teeth on the left side for dental age estimation. Chaillet and Demirjian modified the original method to incorporate the use of 3rd molars and published regression formulae for dental age estimation.[28] Acharya, however, determined that this 8 teeth method was also inaccurate for the Indian population, and derived new regression formulae to suit the Indian population.[29] Similarly, the original Willems method used the seven mandibular left teeth and had gender-specific data for dental maturity scores. Willems et al revised the same in the year 2010 and published new charts with gender-neutral dental maturity scores for the seven teeth.[30] The applicability of these modified age estimation methods has been poorly studied in the Indian population until date.

Studies in the past have determined that Willems method is suitable to use in Japanese children,[31] children from the Former Yugoslav Republic of Macedonia,[32] Turkish children,[33] etc. in addition to the original study population of Belgium. Our findings suggest that Willems method is also equally applicable to the Indian population. It is possible that with more population data and improved standardization, Willems method can be made more useful on a global scale.

It is important to acknowledge that there are some pitfalls in the included studies, and in many similar age estimation studies reported previously. Very few studies in the past have reported the standard procedure for determining the chronological age of their samples. Since most studies report an underestimation or overestimation in the range of days or few months, it is essential that the chronological age be established as accurately as possible. Also, we found that many published studies had incomplete data, which resulted in the rejection of almost 14 such reports in our meta-analysis. It is important that authors and editors realize that at least a bare minimum of data needs to be published to ensure that the findings may be consolidated at a later date.

CONCLUSIONS

Willems' method predicted the chronological age more accurately than Demirjian's method in the Indian population, irrespective of gender. It may be used for age determination for forensic purposes if the levels of accuracy are acceptable. Further studies from other regions of India would help determine whether any modifications or corrections are needed, or whether this method may be used as is.

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Digital tooth reconstruction: An innovative approach in forensic odontology

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KEYWORDS

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ABSTRACT

In mass disasters, accidents and crime investigations, where human remains are decomposed, charred or skeletonized, teeth may dislodge due to post-mortem loss or due to mishandling of evidence during the manipulation of skeletal and dental remains. Thus, the identification process is hampered due to the loss of dental evidence. In these situations, forensic tooth reconstruction may aid in the identification process. Forensic tooth reconstruction (FTR) refers to the process that aims to reconstruct the morphology of the missing tooth from the skeletal remains from the intra-alveolar morphology of the dental socket. The study is an innovative attempt to develop a digital approach to reconstruct three-dimensional (3D) printed tooth models through recording intra-alveolar morphology of empty dental sockets which simulate the teeth which are missing post-mortem. An experimental study was conducted on the human mandible, where using volumetric scanning, 3D scanning and printing techniques the tooth was reconstructed from the intra-alveolar morphology of the socket. Through metric analysis and qualitative congruency testing it was established that there was minimal discrepancy between natural tooth and 3D printed tooth. It was determined that teeth missing post-mortem do not necessarily invalidate the identification process. Digital FTR gives accurate results with minimum error.

INTRODUCTION

Digital dentistry has taken over conventional dentistry in recent times through three dimensional (3D) scanning, computer aided design or computer aided manufacturing (CAD/CAM), and rapid prototyping.[1] In prosthetic treatments, computerized scanning and 3D printing systems have come to largely replace traditional techniques for producing various prostheses.[2] 3D printed models and surgical guides help the dentists plan complicated non-surgical and surgical endodontic treatments, by using cone beam computed tomography (CBCT). CBCT has an added advantage as it provides undistorted three-dimensional, volumetric information of the maxillofacial skeleton[1] thus providing enhanced results.

As forensic odontology often deals with the "who" part of an investigation i.e. establishing the identity of an individual, it demands the highest possible degree of accuracy to give a positive identification.[3] Teeth, especially the enamel, being the most calcified structures in the human body, are found to be common remains in mass disaster events.[4] However, in some unusual instances, teeth may be dislodged due to post-mortem loss or due to mishandling of evidence during the search and recovery process. Moreover, careless handling in collection, transportation, packaging and dispatch for examination of human remains from crime scenes or in exhumations may further contribute to tooth loss.[5] In such extreme situations, the retrieval of the information may become difficult and challenging for forensic odontologists as teeth are unavailable for examination. Here, reconstruction of tooth morphology may aid in the identification process.

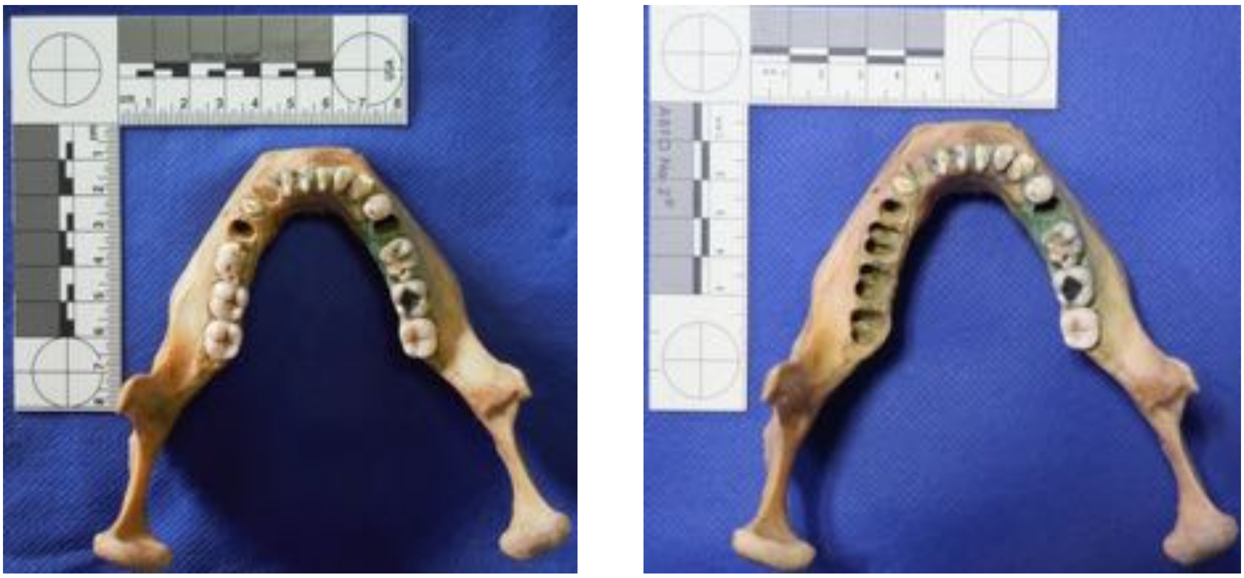
Forensic tooth reconstruction (FTR) refers to the process that aims to reconstruct the morphology of the missing tooth from the skeletal remains from the intra-alveolar morphology of the dental socket.[6] Amalgamation of digital dentistry with tooth reconstruction techniques, can simplify the identification process with minimized manual errors for reconstruction of a tooth. The study is an innovative attempt to develop a digital approach to reconstruct three-dimensional (3D) printed tooth models through recording intra-alveolar morphology of empty dental sockets which simulate the teeth missing post-mortem.

MATERIALS AND METHODS

Data Acquisition

In this in-vitro experimental study, a human mandible with known age, sex and race was obtained from the skeletal archives of Laboratory of Forensic Odontology, Gujarat Forensic Sciences University, Gujarat, India. The mandible possessed the following teeth: left third molar (38), left second molar (37), left first molar (36), left first premolar (34), left lateral incisor (32), left central incisor (31), right central incisor (41), right lateral incisor (42), right canine (43), right first premolar (44), right first molar (46), right second molar (47), right third molar (48), and the teeth present were noted and recorded by the Fédération Dentaire Internationale (FDI) notation (Figure 1a). Later on, the following teeth were removed manually from the sockets, without damaging the socket's structural integrity, simulating teeth missing post-mortem: left third molar (38), left second molar (37), and left first molar (36) (Figure 1b). Intra-alveolar inspection was performed by two examiners, independently, to verify morphological integrity of the socket and the lack of foreign bodies. The entire study was conducted in two phases, phase 1, which comprised 3D scanning and printing the skeletal remains (mandible), and phase 2, which comprised 3D modelling and printing the teeth.

Figure 1. Occlusal view of human mandible; before removal of teeth (a) and after removal of teeth (b)



Phase 1: 3D scanning and printing the mandible

The bone was scanned at Scanmax Dental Imaging Centre (Ahmedabad, Gujarat) by an on-site dental radiographer using a Care stream 9300 premium cone beam computed tomography scanner (Figure 2a). Scanning parameters were – field of view (FOV) 5*5inch, exposure 10 seconds, at 88 kVp, 10 mA). The CBCT images were saved as Digital Imaging and Communications in Medicine (DICOM) data and were transferred to a compact disk (CD). Later, the DICOM data was reconstructed using CS 3D imaging software version 3.8.7. A surface model of the mandible was generated by using (DDS-Pro) and then exported as an STL (stereolithography or standard tessellation file). Then, the STL files were prepared for printing using a 3D printer (da Vinci Jr. 1.0 by XYZ Printing) using poly lactic acid (PLA) material by fused deposition modelling (FDM) technology (Figure 2b).

Figure 2a. Phase 1- Acquisition of data by volumetric scanning (CBCT)

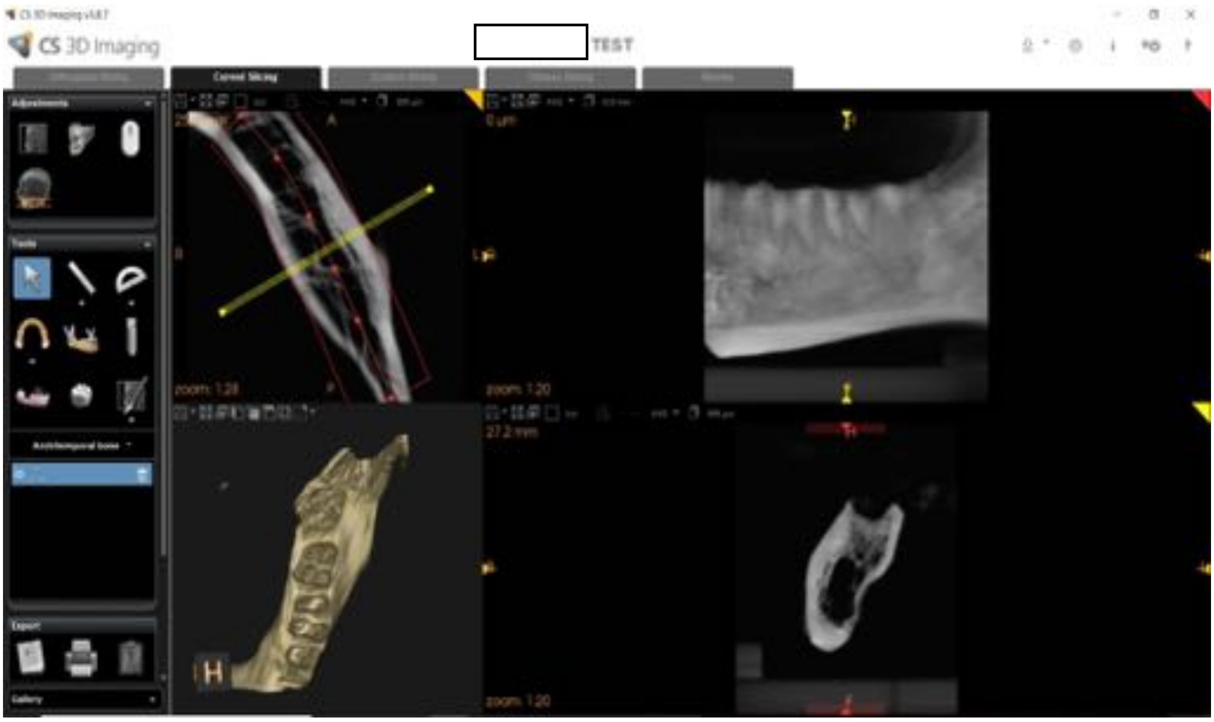
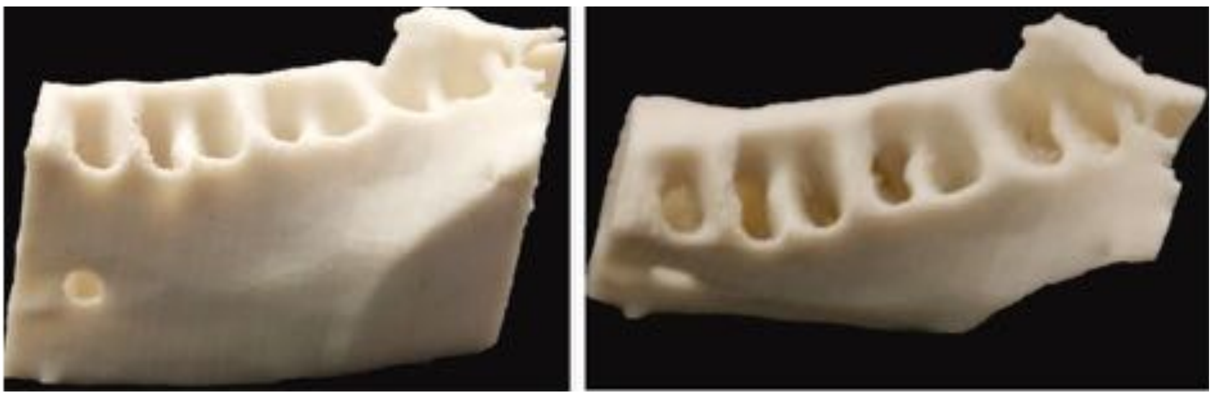


Figure 2b. Phase 1- Three dimensional (3D) printed mandible model



Phase 2: 3D reconstruction and printing of the teeth

Firstly, the intra-alveolar impression of the 3D printed mandible was taken using a combination of very heavy body (putty) addition silicone (Adsil Acura Soft Putty - ADA Sp.no 19) and light body addition silicone (Aquasil Ultra LV/XLV Smart Wetting® Regular Set, Densply -ADA Sp.no 19) (Figure 3a). Thereafter, the impression was scanned using a structured-light 3D scanner (Neway, Open technology) with an accuracy of 0.02 mm (Figure 3b) and consequently, using Exocad dental software, root digital models were prepared and the crown was constructed digitally using ideal measurements used for a prosthetic cad-cam crowns (Figure 4a).

The STL files were prepared for printing using stereolithography (SLA) 3D printer Nobel 1.0 by XYZ printing. Here, the tooth was printed using clear photopolymerizing resin by a Nobel 1.0 SLA printer by XYZ printing (Figure 4b).

Figure 3a. Phase 2- Intra-alveolar impression of printed mandible

Figure 3b. Phase 2, Surface scanned impression

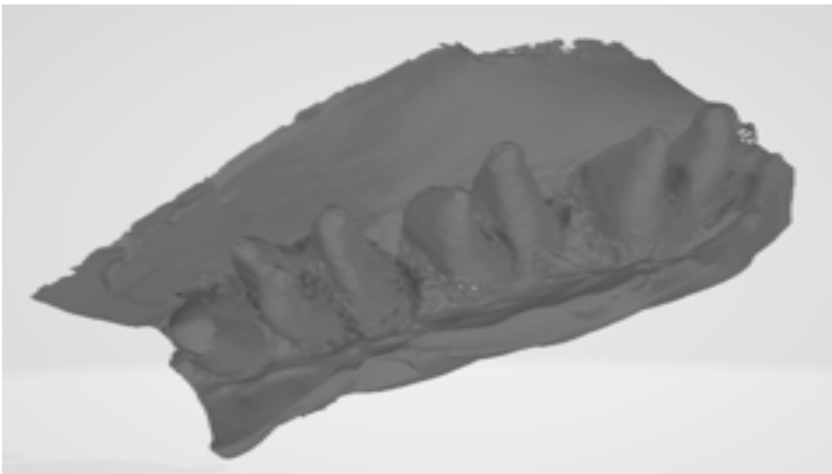


Figure 4a. Phase 2- Tooth reconstructed digitally using CAD software

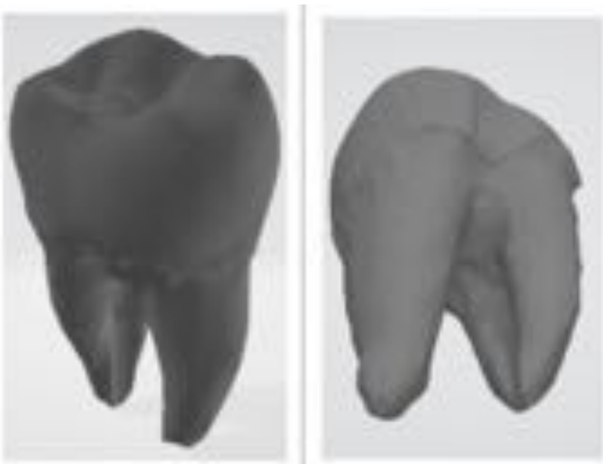


Figure 4b. Phase 2- 3D printed Tooth

RESULTS

Morphological Analysis

The reconstructed teeth were compared with the reference teeth for morphological analysis. It was observed that the anatomy of the reconstructed root resembled the anatomy of the natural tooth root (Figure 5).

The radiographic assessment was done with digital radiovisuography (RVG) (Vatech, at 60kvp/2.5ma,0.12 sec) to assess the adaptability of the teeth in the socket. The material used for printing the teeth was radiolucent and hence the radiograph showed the shadow of the tooth, which showed appropriate adaptability (can be seen by arrows) (Figure 6).

3D Digital Analysis

The utilization of different coloured images allowed a qualitative congruency analysis between reference teeth and reconstructed teeth as show in (Figure 7). The maximum error range was set between -0.5mm and +0.5mm. The areas of positive error are represented by the yellow and red regions, and the areas of negative error are represented by the blue regions. Areas where the error is near zero are represented by the green regions. The mean ± standard deviation (SD) of the RMS values is 0.44 ± 0.5 mm, representing the overall level of 3D morphological error. The average value and variance are represented as 0.24 mm and 0.19 mm respectively.

3D odontometric measurement error

Odontometric measurements

Various linear odontometric measurements of the teeth were obtained from the reference teeth and 3D printed replicas to evaluate the accuracy of the reconstruction approach (Table 1). Also, the following measurements were taken using a digital sliding calliper:

1. Root length error (RLM Error) on mesial aspect = Root length of reconstructed tooth - Root length of reference tooth.
2. Root length error (RLD Error) on distal aspect = Root length of reconstructed tooth - Root length of reference tooth
3. Crown length error (CL Error) = Crown length of reconstructed tooth - Crown length of reference tooth
4. Crown to furcation length error (CFL Error) = Crown to furcation length of reconstructed tooth - Crown to furcation length of reference tooth
5. Mesio-distal dimension error (MD Error) = Mesio-distal dimension of reconstructed tooth - Mesio-distal dimension of reference tooth.

On the basis of the odontometric measurements, the minimum RLM error obtained was 0.28mm whereas the maximum was 0.74mm. The minimum and maximum RLD error was 0.26 mm and 0.68mm respectively. For CL the minimum error was 0.38mm and maximum error 0. 46mm.The minimum and maximum CFL error recorded was 0.38mm and 1. 21mm.The MD error was 0.49mm and 0.58mm

Figure 5. Comparison with Natural Tooth

Figure 6. Radiographic assessment

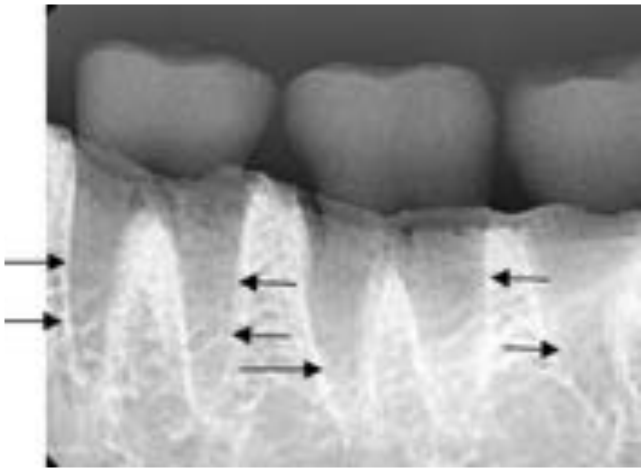


Figure 7. Digital analysis of reconstructed tooth

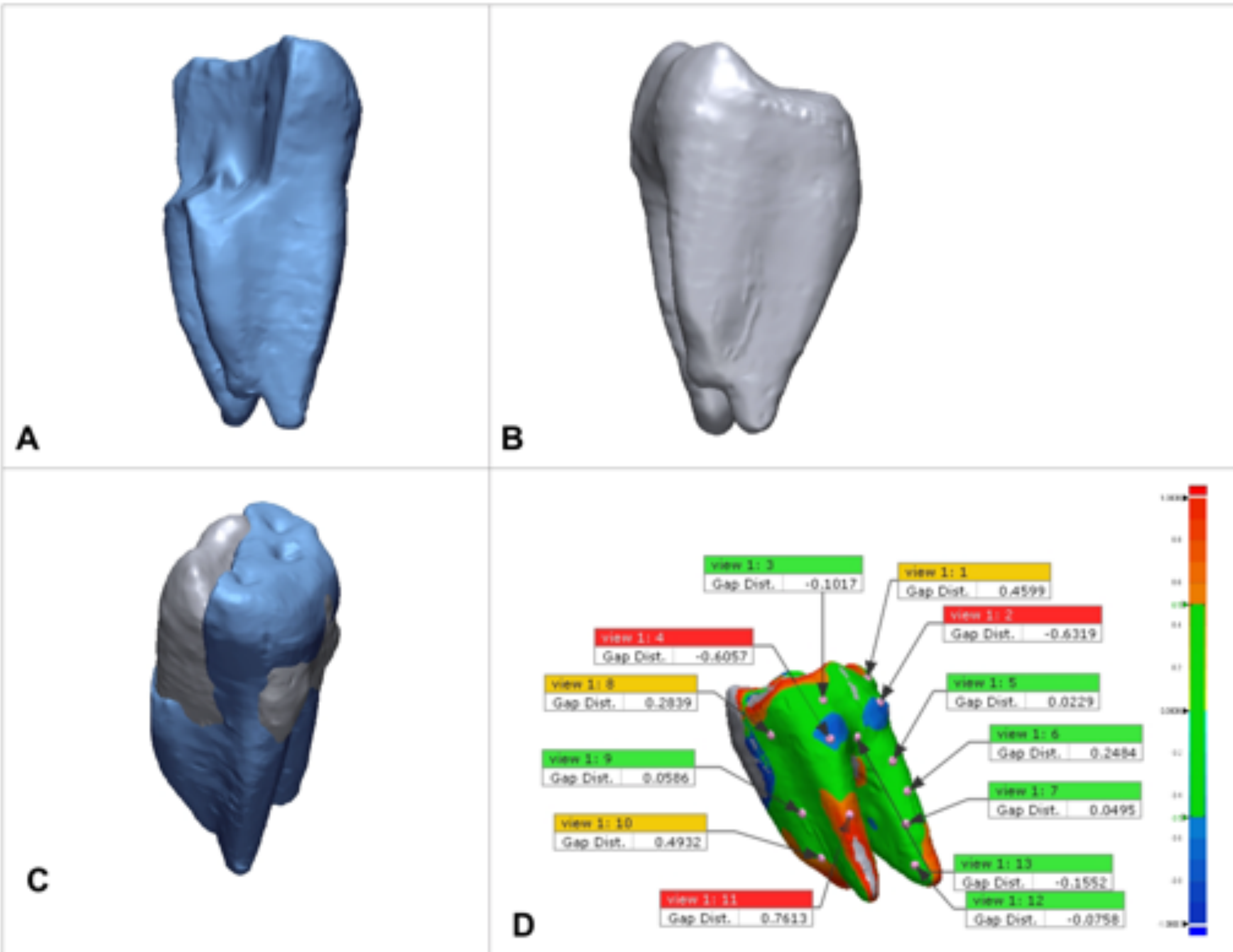


Table 1. Odontometric analysis of natural tooth and digital tooth with their error rate

Crown-Root Dimensions	Dimensions of 36		Dimensions of 37		Dimensions of 38	
	Natural Tooth (in mm)	Digitally reconstructed tooth (in mm)	Natural Tooth (in mm)	Digitally reconstructed tooth (in mm)	Natural Tooth (in mm)	Digitally reconstructed tooth (in mm)
Root Length (Mesial)	9.81	9.53	11.37	10.63	10.71	10.34
Root Length (Distal)	9.90	9.22	12.13	11.58	9.27	9.01
Crown –Length	5.38	5.00	6.56	7.02	6.51	6.11
Mesio-Distal Width	10.60	10.02	10.15	10.81	10.67	10.12
Crown Length to furcation	9.05	7.84	10.09	10.58	10.48	10.10
RLM Error	-0.28		-0.74		-0.37	
RLD Error	-0.68		-0.55		-0.26	
CL Error	-0.38		0.46		-0.40	
CFL Error	-1.21		0.49		-0.38	
MD Error	-0.58		0.49		-0.55	

DISCUSSION

Dental identification assumes a key role in the identification of remains when post-mortem changes, traumatic tissue injury or lack of a fingerprint record invalidate the use of visual or fingerprint methods.[7] Identification through dental remains is of primary importance when the deceased person is skeletonized, decomposed, burned or dismembered.[7] Teeth can provide decisive information for human identification even when they are missing by examining the alveolar bone[8] and intra-alveolar morphology.[9] Post-mortem tooth loss is common in cases of skeletonized or incinerated remains due to loss of periodontal tissue or due to improper handling of the evidence. This dislodgement and loss of teeth may cause complexity in case solving processes[10] and hence hamper the process of identification. Thus, to overcome the hurdles in post-mortem examination in 2018, the authors[6] made an attempt to reconstruct the teeth with dental materials by recording the intra-alveolar morphology of the dental root socket. The reconstructed tooth root showed a discrepancy of 0.5-1mm and thus validated that the dental information can be retrieved even if the teeth are missing post-mortem[6]. With advances in technology and the introduction of computer assisted system for dental identification,[11] the present study was designed to reconstruct the tooth using, volumetric data acquisition, 3-dimensional (3D) scanning and 3D printing techniques.

3D printed replicas of bones have been used as supporting evidence in courts of law in several countries.[12-14] The use of a 3D printed tooth to study the anatomy in complicated endodontic cases has been widely documented,[15] however their use in forensic is yet to be explored. The presently described technique has an added advantage in cases of charred and brittle remains as the model is directly printed using volumetric scanning and 3D printing technique which eliminates the use of alginate or silicone base for replicating the evidence. The use of these materials on brittle remains may cause damage to the remains,[16] something which the use of this technique eliminates. Generally, trueness is a term used to measure the accuracy. It is defined as the comparison between a reference dataset and a test dataset. A higher trueness value results in close or equal to the real value of the measured object. In this technique, the scanned data presented with trueness of 0.03mm. The final 3D printed models produced were on average accurate to the source teeth, with mean differences of 0.24 mm within the accepted range of ±1.00 mm hence proving digital method delivered a minimal loss of structural integrity when compared with the original tooth structures. Thus, digital tooth reconstruction could be a method of choice for accurate results. Adequate precise results were obtained even in cases of dilacerated roots which was critical in conventional reconstruction. The printed tooth can be used as evidence in a court of law and a model that would aid in various investigative procedures for various metric and non-metric analyses. The reconstructed tooth root would also aid in comparative root identification when ante-mortem records are available as the root traits are potentially distinct; especially in population differentiation, in cases such as mass disasters, where the victims might hail from different countries and continents.[17] This would also assist in swift and accurate morphometric analysis of roots. Recent studies have also stated that root length may help in sex determination,[18] hence a reconstructed root may be an aid in this. The intra-alveolar morphology reproduced enables assessment of the root developmental stage that might also aid in age estimation, [17,19] though further studies are indicated in this field. Apart from comparative identification, it may also help in reconstructive identification. The position and protrusion of the teeth would also play an important role in determining the shape, thickness and position of the lips[16] thus the reconstructed tooth would ultimately be beneficial in forensic reconstruction.

The limitation of the present approach is that it requires expert intervention/multi-disciplinary approach, quite expensive and cannot be used in cases where the socket walls are damaged or fractured. However, with technological and technical advancements, the costs are bound to reduce, and the use of this method might become more feasible.

CONCLUSION

A digital approach was developed using 3D technology viz. surface and volumetric scanning, and also 3D printing which showed appropriate morphology visually, when compared with the original teeth. The reconstructed teeth showed appropriate adaptability in radiographs. The reconstructed teeth were digitally compared with the teeth removed from the socket by qualitative congruency analysis which showed the error range of 0.44 ± 0.5 mm, which was below the maximum allowable range of ±0.5 mm. The odontometric measurements of the teeth obtained from the reference teeth and 3D printed teeth showed the average error of 0.24 mm. Thus, it can be stated that the 3D replicas can serve as useful evidence in case of post-mortem tooth loss, giving accurate results with minimum error. With the introduction of newer technologies in future, studies that address the limitations inherent to the present approach can be considered.

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Personal identification through digital photo superimposition of dental profile: a pilot study

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ABSTRACT

The usefulness of teeth for personal identification lies mainly in their vast individual variability, making them virtually unique for every subject. Odontological identification represents a reliable and important complement to forensic inquiries, in particular in the event of unidentifiable human remains. However, this technique is based on the availability of ante-mortem records containing significant evidence. In the absence of dental records, the only available ante-mortem elements are often photographs. In the present study, dental profile photographs of selected smiling subjects were compared to the relevant plaster study models through digital image analysis. In order to ascertain the reliability of the technique, the comparison was carried out both in a homologous and heterologous manner with the Facecomp software. The results confirm the ability of Facecomp software to identify even the smallest variations in dental elements to reach a positive identification. The method is useful in forensic practice since a forensic inquiry may obtain plaster models from cadavers for comparison with photographs of missing people's anterior teeth.

INTRODUCTION

The usefulness of teeth for personal identification lies mainly in their vast individual variability, making them virtually unique for every subject.[1]

Therefore, dental identification represents a useful technique for personal identification based on ante-mortem records comparison (such as x-rays, plaster study models, palatine rugae and information contained in dental/medical records) with post-mortem records. However, obtaining adequate ante-mortem dental records is not always possible and this is particularly true in Italy where the number of illegal immigrants are on the rise. Indeed, in such cases, most of the available material is represented by photographs obtained from friends and acquaintances through which we attempt to identify an unidentified body. This can be achieved through the technique of photographic superimposition. Such a technique is even more reliable than craniofacial superimposition where the comparison is carried out between facial soft tissues and cranium skeletal structure.[2-6] With dental profile superimposition, the only skeletal elements, teeth are compared, even in a living subject.

There is little evidence of studies employing dental superimposition.[7,8] The purpose of this study is to offer an additional contribution by testing a superimposition methodology as standardised and reproducible as possible using photographs of selected smiling subjects, where teeth are sufficiently visible and then compared with plaster model photographs obtained from the subjects' dental records. Furthermore, the procedure of records' acquisition and model production is reproducible on cadavers.

MATERIALS AND METHODS

A set of 10 photographs of 10 subjects (5 males and 5 females) were taken. They were asked to smile in a natural manner to expose their upper teeth, from canine to canine. Photographs were taken with a high-resolution camera (*Canon, model EOS 500D*).

Dental records were also obtained from the same subjects so that a plaster model could be made for each individual. All models obtained were then photographed in occlusion, using the same camera.

The photographs were uploaded onto a computer and a first comparison between the subjects and the study models was carried out by using Adobe Photoshop software (*Adobe Systems, Version 7.0 pro, San Jose, California, USA*). With such software, the photograph of each subject was superimposed on that of the relevant study model.

The image obtained was superimposed while keeping the same proportions ("block proportions" tool), then two levels of superimposition were created where one image was in the forefront compared to the other:

- Level 1: study model;
- Level 2: subject's teeth.

Thanks to the "blending" effect, superimposition was gradually processed (starting from 0% and rising to 50% and 100%).

Such a procedure was necessary to avoid distortion by obtaining a photograph of the teeth and the model of the same size for each subject.

Images obtained with Photoshop were uploaded onto Facecomp software. This software, designed by the engineering department of Bari University, is able to compare two geometric figures starting from selected points on the photographs. This software allows matching two geometrical figures through selected points, such as certain anatomical landmarks. These are identified and marked on each photograph (of natural teeth and of models) and the software automatically supplies measurements on: absolute distances, relative distances, shape factors (a value that numerically describe the shape of a particle, independent of its size), moments (a quantitative measure of the shape of a function), perimeter, and area of a polygon obtained by joining landmarks.[9]

For example, the algorithms parameters for perimeter and shape factors were calculated as follows:

Let x_i and y_i be the generic coordinates of a point, I, J and K the points of a generic triangle, and p_{ijk} the perimeter of the triangle; the area can be obtained in the following way:

$$area\_tri = 1/2 Abs \left(\begin{vmatrix} x_i & y_i & \\ x_j & y_j & \\ x_k & y_k & 1 \end{vmatrix} \right)$$

Where *Abs* is the method for the solution of general linear algebraic systems.

The related compactness index is as follows:

$$comp\_ind = area\_tri / p2ijk$$

The index, as a shape factor, is a dimensionless value and describes the irregularity of the represented geometric figure[10].

The software Facecomp includes the following functions:

-Interactive landmark point fixing for the morphometric analysis;

-Computing and visualization of parameter sets for each image analysed;

-Automatic calculation and presentation of comparison results.

The photographs of the 10 smiling subjects and those of the study models (100% opacity) were then uploaded onto Facecomp. Then, one examiner selected 5 anatomical landmarks in order to carry out the next comparison. The anatomical landmarks were selected as (Figure 1):

1. and 2. Landmarks for the two upper canines (left and right), on the cusp tip, called *left canine* and *right canine*;

3. One in the middle of the interdental area between the two upper central incisors, locating it at half the coronal length of the incisors, called *median line*;

4. and 5. Landmarks in the intersection of the central incisor's distal margin with the lateral incisor's mesial margin to the right and to the left respectively, called *right incisor* and *left incisor*.

The 5 points were identified, for each subject, on both pictures (Figure 2) imported with Facecomp.

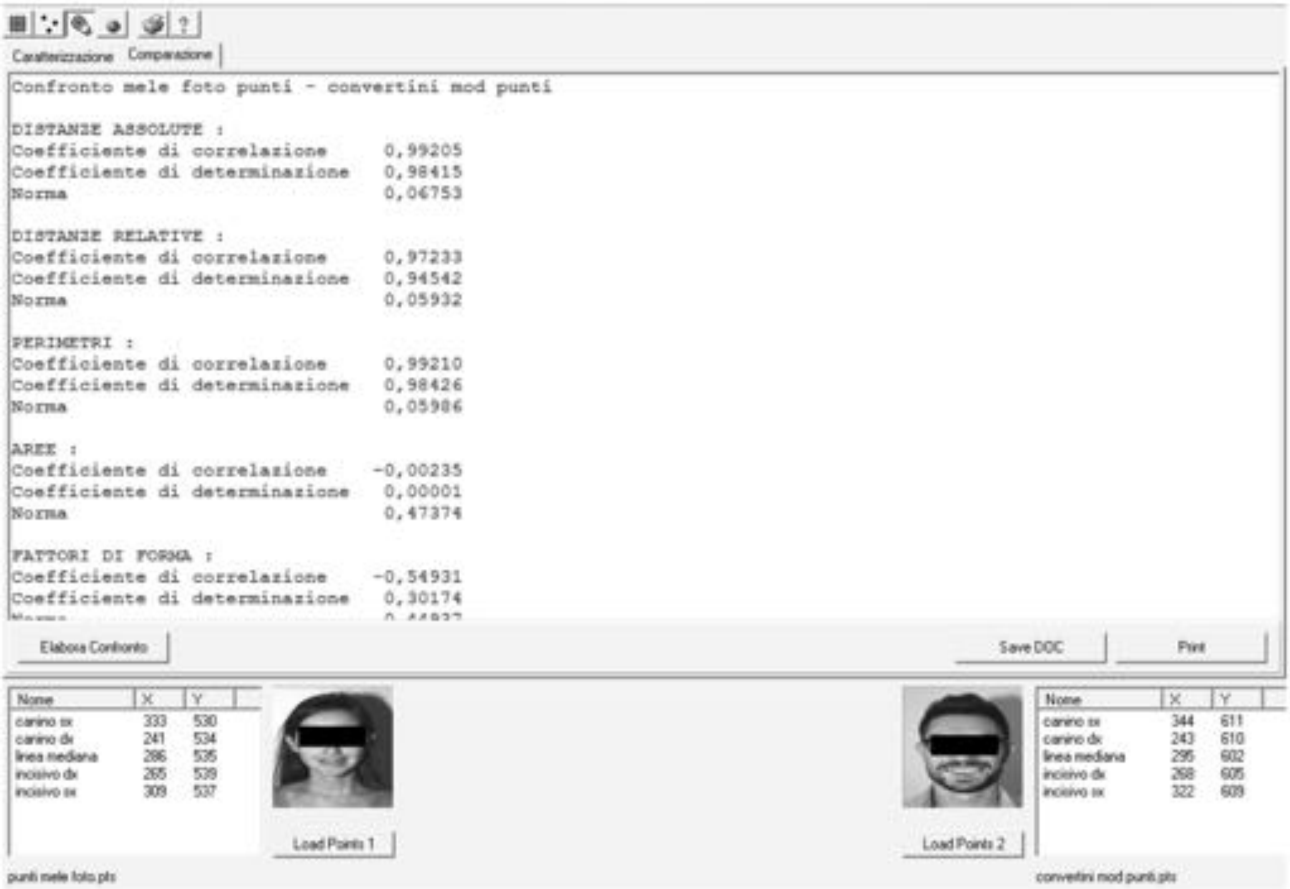
Figure 1. Anatomical landmarks

Figure 2. Examples of superimposition study and positioning of anatomical landmarks

The comparison was carried out with homologous pairs (photograph of the subject smiling with their superimposed plaster model) and with heterologous pairs (photograph of the subject smiling with the study model belonging to a different subject) to identify possible differences in data obtained.

Thus, a comparison between each pair of photographs was carried out obtaining data relevant to the different parameters provided by the software *(absolute distances, relative distances, shape factors, moments, perimeter, and area of the polygon)* (Figure 3).

Figure 3. Elaboration of comparison in an example of heterologous comparison: results obtained by Facecomp software.



STATISTICAL ANALYSIS

Data were reported in an Excel database and statistical analysis was performed using Stata12MP (StataCorp LLC, College Station, Texas).

Quantitative variables with normal distribution were compared using the Student's t-test, the Mann-Whitney U test was used for non-normally distributed variables. For all tests, a p value of <0.05 was considered as significant.

RESULTS

On the 10 subjects recruited in the study, 10 homologous and 90 heterologous comparisons were carried out. Therefore, the total number of observations amounts to 100. A comparison between the data obtained in the homologous match and that obtained in the heterologous match were compared using statistical analysis. The results of data collected and of the univariate analysis are reported in Table 1 where values with statistical significance ($p<0.05$) have been underlined.

Table 1. Median and average values of variables on total sample, homologous group and heterologous group and comparison between groups.
There was no statistical significance in the comparison between homologous and heterologous match for the values related to absolute distances, relative distances, perimeters, and moments. Data was obtained with statistical significance for the values related to areas and shape factors.

Variable	TOTAL	HOMOLOGOUS	HETEROLOGOUS	P
	Mean ± DS (Range) Median (IQR)	*Mean ± DS (Range) Median (IQR)*	*Mean ± DS (Range) Median (IQR)*	
Absolute distances				
Correlation coefficient	0,9948 ± 0,0045 (0,975 - 0,9997) 0,9962 (0,9926 - 0,998)	0,996 ± 0,0039 (0,9891 - 0,9997) 0,9978 (0,9918 - 0,9989)	0,9947 ± 0,0046 (0,975 - 0,9997) 0,9961 (0,9926 - 0,9978)	0,24§
Coefficient of determination	0,9897 ± 0,0089 (0,9506 - 0,9996) 0,9924 (0,9852 - 0,9959)	0,992 ± 0,0078 (0,9783 - 0,9995) 0,9955 (0,9837 - 0,9977)	0,9895 ± 0,0091 (0,9506 - 0,9996) 0,9923 (0,9853 - 0,9956)	0,24§
Relative distances				
Correlation coefficient	0,9831 ± 0,0133 (0,9326 - 0,9991) 0,9868 (0,9734 - 0,9932)	0,9866 ± 0,0117 (0,9667 - 0,999) 0,9911 (0,9737 - 0,9967)	0,9827 ± 0,0134 (0,9326 - 0,9991) 0,9868 (0,9732 - 0,9926)	0,31§
Coefficient of determination	0,9666 ± 0,0259 (0,8697 - 0,9982) 0,9738 (0,9476 - 0,9865)	0,9735 ± 0,0229 (0,9345 - 0,9981) 0,9822 (0,9481 - 0,9935)	0,9658 ± 0,0262 (0,8697 - 0,9982) 0,9738 (0,9471 - 0,9852)	0,31§
Perimeters				
Correlation coefficient	0,993 ± 0,0075 (0,9585 - 0,9998) 0,9954 (0,9915 - 0,9975)	0,9937 ± 0,007 (0,9824 - 0,9996) 0,9973 (0,9865 - 0,9988)	0,9929 ± 0,0075 (0,9585 - 0,9998) 0,995 (0,9918 - 0,9975)	0,41§
Coefficient of determination	0,9861 ± 0,0147 (0,9187 - 0,9995) 0,9907 (0,9832 - 0,9951)	0,9876 ± 0,0139 (0,9651 - 0,9992) 0,9947 (0,9732 - 0,9976)	0,986 ± 0,0148 (0,9187 - 0,9995) 0,9901 (0,9838 - 0,995)	0,41§
Areas				
Correlation coefficient	0,4031 ± 0,4523 (-0,6857 - 0,9994) 0,5382 (0,1179 - 0,7503)	0,6577 ± 0,4001 (-0,2474 - 0,9865) 0,8173 (0,5827 - 0,9113)	0,3748 ± 0,4508 (-0,6857 - 0,9994) 0,4896 (0,0413 - 0,7306)	0,02§
Coefficient of determination	0,365 ± 0,2883 (0 - 0,9989) 0,3283 (0,0904 - 0,563)	0,5767 ± 0,3368 (0,0248 - 0,9732) 0,6684 (0,3395 - 0,8304)	0,3415 ± 0,2746 (0 - 0,9989) 0,2903 (0,079 - 0,5338)	0,03§
Shape factors				
Correlation coefficient	0,3004 ± 0,5112 (-0,8768 - 0,9997) 0,4149 (-0,0809 - 0,7255)	0,6155 ± 0,4599 (-0,545 - 0,99) 0,8077 (0,4507 - 0,8728)	0,2654 ± 0,5068 (-0,8768 - 0,9997) 0,3565 (-0,1343 - 0,6761)	0,02§
Coefficient of determination	0,3502 ± 0,2972 (0 - 0,9995) 0,2548 (0,0898 - 0,5796)	0,5692 ± 0,2908 (0,0925 - 0,9802) 0,6524 (0,2971 - 0,7617)	0,3258 ± 0,2894 (0 - 0,9995) 0,2257 (0,0797 - 0,5406)	0,01§
Moments				
Correlation coefficient	0,9999 ± 0,0001 (0,999 - 1) 1 (0,9999 - 1)	1 ± 0 (0,9999 -) 1 (1 - 1)	0,9999 ± 0,0001 (0,999 - 1) 1 (0,9999 - 1)	0,06§
Coefficient of determination	0,9999 ± 0,0002 (0,9992 - 1) 0,9999 (0,9998 - 1)	0,9999 ± 0,0001 (0,9998 - 1) 1 (0,9999 - 1)	0,9999 ± 0,0002 (0,9992 - 1) 0,9999 (0,9998 - 1)	0,05§

§ Mann - Whitney test

* Student's t-test

DISCUSSION AND CONCLUSIONS

The study demonstrated that the coefficients of determination and correlation of *absolute distances* and that of *relative distances* do not present statistical significance. This can be explained by ethnic anatomical characteristics: the sample includes only Caucasian subjects and, in individuals of the same race, the distance between dental landmarks does not differ substantially[11].

On the other hand, the groups of values with statistical significance are those related to *areas of the polygons* and *shape factors*. These results confirm other studies[9,10]. This pilot study demonstrated the ability of Facecomp software to identify even the smallest variations in dental elements such as length, rotations, diastema as well as the presence of orthodontic devices (present in one of the 10 subjects) and to reach a positive identification even with variable degrees of exposure to dental elements in the natural smile. Therefore, the results obtained have an importance in the identification field. This method may be used in real cases since (after the discovery of a cadaver and following an initial presumptive identification) it is possible to carry out a digital photographic superimposition of dental profile between the photograph of the subject presumptively identified and that of the study model obtained from the cadaver's skull.

It would be appropriate to repeat the study broadening the sample, even to identify a cut-off value above which homology between cast and photograph can be ascertained. Also, different examiners selecting reference points should be tested.

Moreover, in this study, all pictures were taken with the same camera and this enabled us to obtain higher quality photographs compared to common cameras, including mobile phones. Therefore, it would be interesting to assess the superimposition quality obtained with blurrier images or with lower image resolution.

The main aim of this study was carried out in attempting to evaluate a new computer-aided technique of identification, applied with the aim of improving the precision and reliability of personal identification.

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Validation of the third molar maturity index (I_{3M}): study of a Dominican Republic sample

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ABSTRACT
This retrospective study aims to test the third molar maturity index (I_{3M}) cut-off value of 0.08 for 18 years old in Dominican Republic population. Orthopantomograms of 513 subjects (284 females and 229 males) were evaluated, intra- and inter-observer agreement, ICC (intra-class correlation coefficient) values were 0.88% (95 % CI 0.86% to 0.91%), and 0.93% (95% CI 0.90% to 0.96%), for the intra- and inter-observer reliability, respectively. Accuracy in females was 0.96 (95% CI: 0.93-0.97); the sensitivity was 0.99 (95% CI: 0.96-0.99) and specificity was 0.92 (95% CI: 0.86-0.95). In males, the accuracy was 0.96 (95% CI: 0.93-0.98); the sensitivity was 0.94 (95% CI: 0.88-0.97) and specificity was 0.99 (95% CI: 0.95-0.99). The PPV (Positive Predictive Value) was 0.93 for females and 0.99 for males. The results of this study show that I_{3M} can be used for discriminating adults from minors in Dominican Republic subjects around the legal age of 18 years old.

INTRODUCTION
Age estimation in living individuals is often required by authorities when chronological age is in doubt and forensic professionals are usually asked to state their scientific opinion specifically for the legal age of adulthood. In most countries around the world the legal age is 18 years old and it is in this threshold from children to adult that more reliable scientific methods are needed. According with the Code of the minor in the Dominican Republic a person is considered a child from birth to 12 years of age, and an adolescent from 13 to 17 years of age, with majority attained on the 18th birthday. The juvenile criminal justice model adopted by the Dominican Republic, recognizes the young offender's criminal responsibility, making a distinction between social or family conflicts and actual criminal behaviour.[1] The length of penalties involving custody ranges from three years for young people between the ages of 13 and 15 when committing the offence, to five years for young people between the ages of 16 and 18 in similar conditions.[2]
There are several issues that affect the rights of minors in the Dominican Republic such as child marriage,[3] and more increasingly sexual exploitation of minors. The promotion of the Dominican Republic as a tourist attraction has brought a rapid growth in demand of minors to be sexually exploited, a study from 2015 concluded that the prevalence of Commercial Sexual Exploitation of Children in Dominican Republic was

higher in parks, beaches, and street areas, where 23.9% or nearly one in every four individuals observed were under 18. In establishments, such as bars, clubs, and car washes, 5.8% or one in twenty of all commercial sex workers were under 18. A significant majority (92.8%) of these minors were Dominican. The overwhelming majority of minors found engaged in commercial sexual exploitation in the Dominican Republic were between the ages of 15 and 17.[4]

Tourism is one of the main driving forces of the economy of the Dominican Republic and the aim is to reach 10 million visitors for 2022, which would increase the sexual exploitation of minors due to the impunity in which foreign tourists act and the number of unregistered minors. [5]

Due to the many issues involving this vulnerable population the country needs scientific methods that help to assess the critical age of 18 years old. In the Dominican Republic, undocumented minors are evaluated through a radiographic assessment of the left hand, and dental development. Since the third molar is the only tooth still in development after 14 years old, it has been the subject of several studies of age estimation. [6,7]

Cameriere et al in his study from 2008 established a cut-off value for the assessment of 18 years old evaluating the relationship between the open apices and the length of the developing third molar. This cut-off named third molar index (I_{3M}) was set up at 0.08.[8]

The aim of this study is to test the accuracy of the third molar index in evaluating if a subject is 18 years of age or older or not in a Dominican Republic sample of children and young adults.

MATERIALS AND METHODS

A retrospective, cross-sectional study was performed involving the analysis of orthopantomograms of 513 subjects (284 females and 229 males). All the X-rays were randomly collected (consecutive sampling) from the databases of two dental radiological centers: a dental clinic from the University of Santo Domingo (Dominican Republic) and another community dental clinic that includes the provinces of Santo Domingo, La Vega and Santiago. The disparity in the number of X-rays between females and males are a result of following the exclusion criteria that included : patients with facial trauma, gross pathology or history of orthodontic treatment, subjects of unknown age or without full dental records, with no third molars, or third molars with developmental anomalies such as partial pulp development and, finally, overlap of radiopaque structures in the apical third of the tooth that may result in inaccuracies. The radiographs were collected between 2011 and 2018 from individuals aged 14 to 22 years, taken for clinical and/or orthodontic diagnosis, with the presence of the third lower left molar. Age and sex distribution are shown in detail in Table 1.

Table 1. Sample distribution according to sex and age. Numbers in bold represent samples with closed apices of the lower left third molar (I_{3M} = 0.00).

FEMALES			MALES		
Age	N	Closed apex	Age	N	Closed apex
14	31		14	24	
15	33		15	41	
16	32		16	25	**1**
17	22	**1**	17	21	
18	32	**20**	18	22	**12**
19	45	**28**	19	31	**21**
20	45	**39**	20	25	**23**
21	31	**30**	21	28	**28**
22	13	**13**	22	12	**12**
	284			229	

Patient data was recorded in an excel file, along with patients' identification number, sex, date of birth and date of the X-rays. The CA (chronological age) for each subject was calculated by subtracting the date of the X-rays from the date of birth and recorded in years and decimal points. The study was conducted in accordance with the Declaration of Helsinki (Finland).[9]

Measurements

A single examiner (LVP), under blind conditions, performed data collection and, according to Cameriere et al.[8] the ratio between the tooth's longitudinal length and the distances between the inner sides of its roots (I_{3M}) was calculated with the aid of an open source image computer-aided drafting programme, used to process and analyze digital images (ImageJ 1.49). In the case of a tooth with two roots, the sum of the distances of both roots was divided by the tooth length.

Statistical analysis

Two observers (RC and LVP), two forensic odontologists with different experience in dental radiology, analyzed the feasibility and reliability of the paired set of measurements in similar conditions and background. The Intraclass Correlation Coefficient (ICC) was applied to calculate intra- and inter-observer concordance.

Repeated observations from the first author (LVP) were used to assess intra-observer agreement, while inter-observer analysis was based on comparisons with those of another observer. For this purpose, 62 radiographs were randomly selected one month following the initial scoring to calculate percentage of agreement, for both intra- (30 images) and inter-observer (30 images) analysis. Scatter plot and box plot graphs and tables were used to show relationships between chronological age and different I_{3M} values for both sexes.

The data were analyzed on SPSS 22.0 (Statistical Package for Social Sciences) by descriptive statistics and logistic regression, and the threshold of significance was set in all tests at 5%.

Based on the I3M index, radiographs would correspond to individuals aged 18 years or older when the index result was lower than 0.08 (I3M < 0.08).

In order to test the performance of specific cut-off value of I_{3M}, and to determine the sensitivity (the proportion of subjects older than or equal to 18 years of age with $I_{3M} < 0.08$) and specificity (the proportion of individuals younger than 18 with $I_{3M} \geq 0.08$) of the test, a contingency table was used. The performance was assessed also using accurate classification (ACC), Positive Predictive Values (PPV), Negative Predictive Values (NPV) and, finally, positive and negative likelihood ratios (LR+ and LR-).

The I_{3M} may help to discriminate between individuals who are or not aged 18 years, or more, by the post-test probability of being 18 years of age or more (i.e., the proportion of individuals with $I_{3M} < 0.08$ who is older than or equal to 18 years). According to Bayes' theorem, post-test probability is described in the following formula:

$$p = \frac{p_1 \, p_0}{p_1 \, p_0 + (1 - p_2)\,(1 - p_0)}$$

In the post-test probability p, p_0 is the probability that an individual is 18 or older given that he/she is aged between 14 and 22 years, which represents the target population. In this study, probability p_0 was calculated as the proportion of participants between 14 and 22 years of age and those between 18 and 22 years of age who live in the Dominican Republic. This probability, p_0, was evaluated with the data obtained from the Statistical Office of the Dominican Republic [https://www.one.gob.do/#]. The proportion was 0.54 (54.9%) for females and 0.54 (54.6%) for males.

RESULTS

As regards the intra- and inter-observers' agreement, ICC values were 0.88% (95 % CI 0.86% to 0.91%), and 0.93% (95% CI 0.90% to 0.96%), for the intra- and inter-observer reliability, respectively.

The sample distribution consisted of 44.6% males (n = 229) and 55.3% females (n = 284) (Table 1), of which 253 (49.3%) were minors and 284 (55.3%) were 18 years or older. According to the results showed in in the following figures (Figure 1 a and b), the estimated age of majority was correlated with the chronological age (p = 0.000) and the I_{3M} values gradually decreased as age increased in both sexes.

As showed in the Figures 1 A and B, and in the Table 2, the lower third molar mineralization varies according to sex and it occurred slightly earlier in males than in females.

Figure 1. A and B. Boxplots of the relationship between chronological age and I_{3M} in Dominican sample (females and males). Boxplot shows median and inter-quartile ranges, whilst "whiskers" are lines extending from box to highest and lowest values, excluding outliers. The horizontal red dotted line is at 18 years of age.

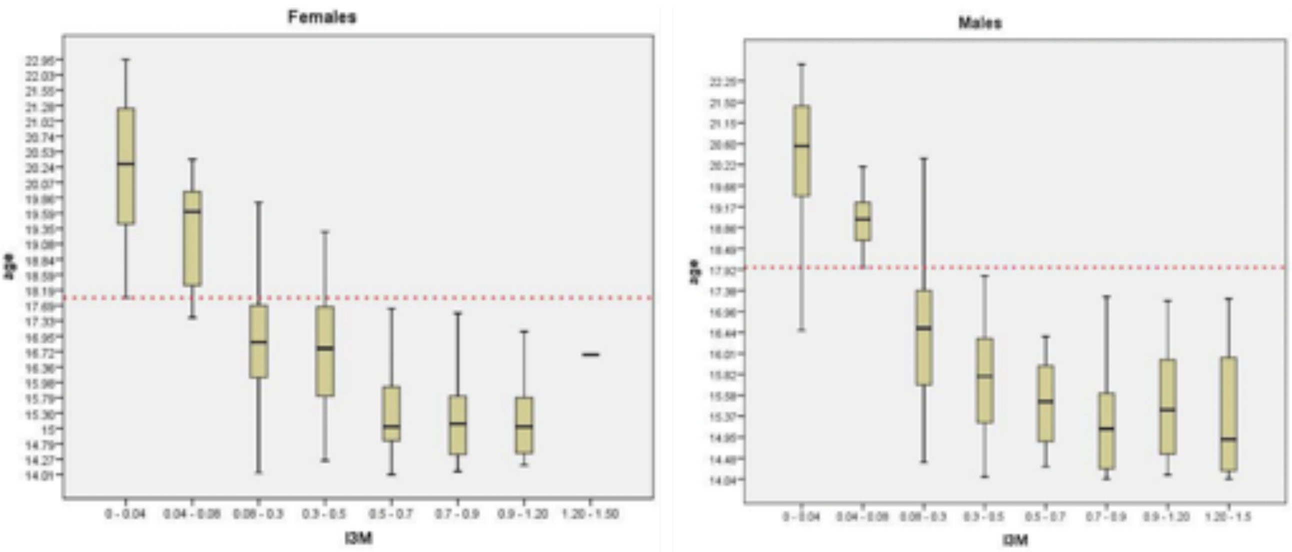

Table 2. Number of individuals mean and standard deviation (SD) of age distribution for each I_{3M} group

I_{3M}	F	Mean	SD	M	Mean	SD
0 – 0.04	135	20.36	1.200	100	20.46	1.328
0.04 – 0.08	16	19.23	0.894	12	18.97	0.592
0.09 – 0.3	53	17.05	1.434	61	16.60	1.261
0.3 – 0.5	26	16.78	1.632	18	15.83	0.968
0.5 – 0.7	21	15.43	1.008	14	15.34	0.642
0.7 – 0.9	20	15.14	0.879	14	15.33	1.281
0.9 – 1.2	12	15.22	0.934	6	15.44	1.137
1.2 – 1.5	1	16.64	-	4	15.26	1.471

in both sexes (F = females; M = males).

Table 3 displays separately the pooled data of sensibility and specificity in both sexes. In females, the accuracy is 0.96 (95% CI: 0.93-0.97); the sensitivity is 0.99 (95% CI: 0.96-0.99) and specificity is 0.92 (95% CI: 0.86-0.95). The PPVs of the test are 0.93 (PPV = True Positives/(True Positives + False Positives)(95% CI: 0.89-0.96); and the NPVs are 0.99 (95% CI: 0.95-0.99). As regard the LR+ and the LR-, the first one is 12.72 (95% CI: 7.01 to 23.06) whilst the second one is 0.01 (95% CI: 0.00 to 0.05). In males, the accuracy is 0.96 (95% CI: 0.93-0.98); the sensitivity is 0.94 (95% CI: 0.88-0.97) and specificity is 0.99 (95% CI: 0.95-0.99). The PPVs of the test are 0.99 (95% CI: 0.95-0.99); and the NPVs are 0.94 (95% CI: 0.88-0.97). Regarding the LR+ and the LR-, their values are 104.42 (95% CI: 14.83 to 735.13) and 0.06 (95% CI: 0.03 to 0.12), respectively.

Table 3. Contingency table of the I_{3M} index for age estimation in both females and males.

Test	Females			Males		
	Age (years)		Total	Age (years)		Total
	≥18	<18		≥18	<18	
(I_{3M}<0.08)	155*	10**	165	111*	1**	112
(I_{3M}≥0.08)	1***	118****	119	7***	110****	117

*True positives; **False positives; ***False negatives; ****True negatives

DISCUSSION

Being able to estimate the legal age of majority (18 years in some countries) through a reliable method is essential for the application of the law. In the Dominican Republic, in the field of civil, criminal and labour law, the method most frequently used to assess adult age in cases lacking documents has been the radiographic analysis of the left hand and wrist bones.

However, several studies have shown the limitation of using this method for adult age due to the difficulty in observing changes in the carpal bones after the age of 14-16 years old.[10,11]

Since chronological age is usually retrieved from birth registration or identification document, it is complex to manage legal situations in which the person has no document or the one they have is not reliable. Third molar development has demonstrated a correlation with legal age of 18 years old.[12,13] A recent systematic review and meta-analysis, regarding how well a fully mature third molar identifies adulthood (> 18 years), concluded that diagnostic accuracy was 71.3% confirming a high correlation. [14]

Based on this well-known relationship between adulthood and third molar development, the I_{3M} was proposed by Cameriere et al. [8] as a simple, user-friendly and inexpensive method based on the relationship between the open apices and the length of the third molar. It established a cut-off of 0.08, in which those resulting in a lower value than the cut-off were positive to the test meaning equal or older than 18 years old while results higher than 0.08 were negative to the test meaning younger than 18 years old. Several samples coming from different continents have been tested, Asia,[15-17] America, [18-21] Africa, [22-24] and Europe. [25-32]

The present study is the first in applying I_{3M} in a Dominican Republic sample and the results are similar with those observed in previous studies in other populations. The accuracy of the I_{3M} in the Dominican Republic was 0.96 both in females and males comparable with results observed in Colombia (0.95 and 0.89), Brazil (0.86 and 0.87), and France with 0.89 and 0.91, for females and males respectively. The results for sensitivity and specificity in this sample were 0.99 and 0.92 for females while for males were 0.94 and 0.99.

The consistency of the results in this study compares with the results obtained from samples from different populations, supports the usefulness of this method, agrees with previous studies,[22-24] and with additional observations made by the systematic review and meta- analysis from 2018. This systematic review assessed the accuracy of I_{3M} for estimating 18 years old from a selection of 16 studies which were used in populations from diverse countries and concluded that this test proved to be suitable for estimating adulthood and therefore the cut-off of 0.08 was regarded as valid to discriminate individuals between adults and minors.[33-35]

The estimation of the age of 18 years is one of the most studied subjects in the forensic field, and the impossibility of having samples to study from every existing population is one of the main problems when validating a method. Testing the reliability of the proposed single cut-off in multiple countries and observing similar results, confirms the application of this method in a subject from an untested population with a fair degree of confidence.

Research emphasizes the need to distinguish minors from adults as a means of protecting a vulnerable population but issues such as sexual exploitation and child brides in the Dominican Republic and around the world do not finish once legal age is attained. Science intervenes by providing means to assist the law, but these studies are also an opportunity to highlight the responsibility of society to not only protect minors but to offer options for those older than 18 so they can have a different choice in life as adults.

Further application of this method in new samples from non-studied nations are necessary. Future research concerning the Dominican Republic population will be done regarding age estimation in children using the same principle of open apices and length of the developing permanent teeth.

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Patient autonomy as a necessary but limited ethical principle in shaping the dentist-patient relationship (*)

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ABSTRACT
Today, the ethical and legal organization of the therapeutic relationship is determined in large extent by the principle of respect for patient autonomy or self-determination. From it, the patient derives important legally enforceable rights, most notably the right to consent to (or refuse) any proposed dental treatment. And yet, historically and indeed by its very nature, this principle is actually foreign to the health care context. Patients do not seek to defend themselves against their dentists in the same way that citizens need protection against a potentially tyrannical government. We will argue that the principle of patient autonomy sets important legal boundaries to the therapeutic relationship. But it does little to cement the relationship itself. Rather, it is the ethical principles of beneficence and non-maleficence that structure the dentist-patient relationship

THE PRIMACY OF THE BIOETHICAL PRINCIPLE OF PATIENT AUTONOMY

The prevailing method of analyzing ethical dilemmas in clinical practice is to apply various principles of health care ethics. Several authoritative lists of such principles exist, ranging from the short three-principle list proposed by the National Commission for the Protection of Human Subjects of Biomedical and Behavioral Research in its groundbreaking *Belmont Report* from 1978,[1] to the *Universal Declaration on Bioethics and Human Rights* adopted by UNESCO in 2005[2] which, depending on how one counts, contains at least 20 principles. The most widely known enumeration is surely the one proposed by the American bioethicists Childress and Beauchamp in their classic handbook *Principles of Biomedical Ethics*, first published in 1979[3] and currently in its eight edition[4]: Autonomy, non-maleficence, beneficence, and justice.

As the order of the Beauchamp & Childress list suggests, the principle of autonomy – or as it is known in full, the principle of respect for patient autonomy – is generally considered to be the most important principle. A cursory review of the scientific literature likewise reveals that of these four, the principle of autonomy is discussed far more often than any of the other three principles (see Table 1).

One also finds this principle back in many professional codes of ethics, including codes of dental ethics. When in 1996 the American Dental Association (ADA) decided to completely restructure its Code around five principles, the first listed was the principle of autonomy.

Table 1. PubMed Search Results

The Primacy of Autonomy: PubMed					
Ethics AND AND		Autonomy	Justice	Nonmalefice nce	Beneficence
	206,230	20,072 (9.7%)	13,775 (6.7%)	4,067 (2.0%)	4,006 (1.9%)
Dentistry	3770	279 (7.4%)	177 (5.0%)	97 (2.6%)	94 (2.5%)
Pharmacy	2039	93 (4.6%)	52 (2.6%)	37 (1.8%)	35 (1.7%)
Nursing	22,337	2,571 (11,5%)	1,173 (5.3%)	558 (2.5%)	554 (2.5%)
Ethics AND AND		Autonomy*	Justice**	Nonmalefice nce	Beneficence
	206,230	18,879 (9,2%)	13,633 (6.6%)	4,067 (2.0%)	4,006 (1.9%)
Dentistry	3770	246 (6,5%)	176 (4.7%)	97 (2.6%)	94 (2.5%)
Pharmacy	2039	83 (4.1%)	51 (2.5%)	37 (1.8%)	35 (1.7%)
Nursing	22,337	2,107 (9,4%)	1,168 (5.2%)	558 (2.5%)	554 (2.5%)

* ANDNOT "professional autonomy" ** ANDNOT "justice system"

The 2018 version of the ADA's *Principles of Ethics and Code of Conduct* defines autonomy as "self-governance" and then elaborates that "the dentist has a duty to respect the patient's rights to self-determination and confidentiality."[5]

It is debatable whether the duty to maintain confidentiality can be subsumed under the principle of patient autonomy.* Suffice it to say here that respect for the patient's autonomy – a Greek word variously translated as self-law, self-governance, and self-determination – requires the dentist "to treat the patient according to the patient's desires, within the bounds of accepted treatment.... Under this principle, the dentist's primary obligations include involving patients in treatment decisions in a meaningful way, with due consideration being given to the patient's needs, desires and abilities...". Practically, this means that "the dentist should inform the patient of the proposed treatment, and any reasonable alternatives, in a manner that allows the patient to become involved in treatment decisions".[6]

Similar language can be found in other codes of dental ethics. For example, the Canadian Dental Association *Principles of Ethics* from 2015 includes the principle of "respect for autonomy" which it defines as "respect the patient's right to choose." The document elaborates that "patients have the right to be fully informed and make choices for, and actively participate in, their care and pursue their personal values, beliefs and goals in achieving their optimal oral health."[7] The German Dental Board in its 2017 *Code of Professional Conduct* includes in §2 on professional duties the statement that "the dentist is in particular obligated to respect the patient's right to self-determination."[8] And the Indian Dental Association's *Ethics Code* includes in the section on "Duties of Dental Practitioners to Their Patients" a paragraph entitled "Patient Autonomy": "The patient has the right to choose, on the basis of adequate information, from alternative treatment plans that meet professional standards of care."[9]

Some codes of dental ethics do not specifically mention autonomy, but go directly to the single most important operationalization of this ethical principle, that is, the duty to obtain patient consent prior to treatment. For example, the Royal Dutch Dental Association in its *Code of Conduct* from 2000 notes that "the dentist needs the permission of the patient for the intended examination and the proposed treatment."[10]

A remarkable absentee in this list of codes of dental ethics is the FDI-World Dental Federation. The FDI's *International Principles of Ethics for the Dental Profession*, adopted in Seoul, Korea in 1997, makes no mention of patient autonomy nor of the patient's right to consent to or refuse a proposed intervention.[11] The closest reference to the principle of respect for patient autonomy surfaces in the FDI's the *Basic Rights* *and Responsibilities of Dental Patients*, adopted in Dubai, UAE in 2007.[12] There we find that dentists must exhibit "necessary concern for [patients'] reasonable preferences"; furthermore, dentists must provide patients with "encouragement to participate in decision-making processes affecting their oral health care." But as the quotes make clear, these obligations are not formulated in very strong terms ("concern" instead of "respect" for patient preferences, and "encouragement to participate" instead of a "right to consent").

The FDI, while an exception among the other dental associations discussed above, is not completely aberrant in its failure to assign the principle of respect for patient autonomy a prominent place among the norms guiding dental practice. There are two good reasons for not doing so. The first is historical, the second concerns the scope of patient autonomy.

SOME NOTES ON THE HISTORY OF THE PRINCIPLE OF PATIENT AUTONOMY

Historically, we need to be mindful that the principle of patient autonomy is a very modern invention, roughly one century old. In that sense, it stands in marked contrast to the principles of beneficence and non-maleficence. We can find the latter two already in the *Hippocratic Oath*.[13] In fact, each of them is referenced twice: "I will use treatment to help the sick according to my ability and judgment, but never with a view to injury and wrong-doing. ... Into whatsoever houses I enter, I will enter to help the sick, and I will abstain from all intentional wrong-doing and harm." But one looks in vain for a reference to the concept of patient self-determination, right to choose, or consent. The same is true for later, pre-20th-century oaths and codes. And why would there be such a reference? For on closer inspection, it seems rather odd to place so much emphasis on patient self-determination. For isn't it exactly the disease-induced inability of a person to lead life as (s)he sees fit that brings that person to visit a health care professional? And isn't it exactly the professional's expertly designed treatment plan that will benefit the patient while minimizing harmful side-effects, and that the patient hence desires so as to restore his/her own ability to live life as (s)he sees fit? So why this emphasis on patient self-determination, choice and consent?

If one could ask the author of the Hippocratic Oath why he had failed to include patient autonomy, he would have likely responded that this principle does not need to be included as long as the physician takes the principles of beneficence and non-maleficence seriously. It is only if we distrust the intentions and/or abilities of service providers to competently care for us that we need something like a principle of respect for autonomy. But the relationship between health care provider and patient is one of trust, a fiduciary relationship.

Or is it? Is the therapeutic relationship still essentially a relationship of trust? The Canadian Dental Association in the aforementioned *Principles of Ethics* guide insists that "trust is the cornerstone of the dentist-patient relationship and the contract between the dental profession and society." It next lists four specific virtues under the header of trust: Honesty, competence, fairness, and accountability. Interestingly, it does not include "respect for autonomy" in this section (but lists it instead under the header "Health").

The hypothetical response of the author of the ancient Hippocratic Oath and the CDA's placement of the principle of patient autonomy in its 21st century code reflect and important historical change in our understanding of the relationship between health care provider and patient. This change mimics even more dramatic changes that took place in our understanding of the morally right relationship between people in general and those who claim to be their guardians, that is, the government. By the time the United States of America emerged as a new country, the old medieval order in which monarchs were obligated to safeguard the well-being of those they governed, and the people were expected to exhibit trusting allegiance, had been thoroughly uprooted. Instead of trust, consent of the governed became the foundational political principle. The "natural" state of human beings was thought to be one of freedom from such predetermined allegiances and all other communal ties and binds, except if freely engaged in. Or in the words US Declaration of Independence: "Governments are instituted among Men, deriving their just powers from the consent of the governed." [14]

This idea then migrated to other areas of social life in which power differences shape the relationship between people, including the doctor-patient relationship. And so we find, roughly a century after the American Revolution, American courts applying this political principle to the health care context. In 1891, US Supreme Court Justice Gray argued that a person, even one suing for bodily damages, cannot be forced by a court to undergo a medical examination: "No right is held more sacred or is more carefully guarded by the common law than the right of every individual to the possession and control of his own person, free from all restraint or interference of others unless by clear and unquestionable authority of law. ...The right to one's person may be said to be a right of complete immunity; to be let alone" (Union Pacific Railway Co. v. Botsford, 141 U.S. 250 (1891)). Indeed, a surgeon who performs an operation without his patient's consent commits an assault, thus Appeals Court Justice Brandeis (Schloendorff v. Society of New York Hospital, 105 N.E. 92 (N.Y. 1914)).

Maybe even more remarkable than the courts applying to the health care context this new right to be left alone, is the very similar line of reasoning put forward by Pope Pius XII in 1957.[15] While struggling with the question whether and when a physician may apply a life-sustaining medical intervention to an unconscious patient, the Pope considers that "the doctor .... has no separate or independent right where the patient is concerned. In general he can take action only if the patient explicitly or implicitly, directly or indirectly, gives him permission." The Pope does not elaborate on the reasons for this acknowledgment of what we now label as the principle of respect for patient autonomy. But from a Judeo-Christian perspective, we can understand that principle to be grounded in the conviction that human beings must freely accept their own calling and must freely "will" to undertake the actions needed to fulfill that calling. Somebody else cannot fulfill my God-given calling for me.

The latter line of reasoning is analogous to the Kantian understanding of autonomy. The German philosopher Immanuel Kant (1724–1804) is often referenced in contemporary discussions about patient autonomy. In fact, most of these references are highly questionable because Kant's understanding of autonomy has (virtually) no relationship to the contemporary idea of individual self-determination and subjective choice. For Kant, we are autonomous when and because we discern and then freely submit ourselves to rational, universally binding moral rules, as opposed to being guided by other forces such as coercion, appetites, fears, or self-interest (which would render us heteronomous).

A NEGATIVE OR LIBERTY RIGHT

We are now in a better position to define the moral core of patient autonomy: Even if a person is in need of, wants and voluntarily seeks out medical care, the patient's dignity, the inviolability of his/her body, and the individual's right and responsibility to freely do what is good, preclude even the most benevolent health care provider from treating the patient without the latter first authorizing the provider to do so. Consent is a necessary requirement for medical treatment. In other words, somehow consent must be obtained before treatment of any kind can be initiated.

Preferably that consent is an explicit and informed consent given by the patient him/herself. The second best consent is probably an implied consent, that is, a consent implied by a previous explicit act by the patient (e.g., coming to a dentist's office implies consent to the dentist taking a history and doing a basic physical exam). If the patient is not competent to consent, a consent given in advance by the patient while still competent (i.e., in a so-called living will) would be preferable. A substituted consent given by a third person authorized by the patient or a court also qualifies, as does a parental consent for treatment of minors. Finally, there is the option of a presumed consent in case of genuine emergencies. But somehow, consent must be obtained before a medical intervention can be initiated. The good that can come from such interventions, even the good of sustaining human life, does not justify forcing such interventions onto the patient. Ultimately, the patient has a right to be left alone.

In technical terms, this means that patient autonomy generates a liberty or negative right. It is the right to be *free from* medical interventions, that entails a duty on others *not* to do something towards the patient (i.e., *not* to treat). It is important to note that autonomy does not generate a positive right, that is, a claim right or entitlement. Respecting autonomy does not entail a duty on others *to do* something for the patient. Hence, the patient cannot, in reference to the principle of respect of patient autonomy, demand certain medical interventions; the patient can only refuse them. This is because the health care provider likewise has a right to respect of his/her autonomy.

The professional's right to autonomy is admittedly a more limited right than the patient's. For example, it is widely acknowledged that in emergencies, health care providers may not refuse treatment to patients that is urgently needed and that can be competently provided by them. But the provider's own right to professional autonomy does include the right, even the duty, not to embark on treatments that cannot be justified medically, even if the patient wants them.

This also explains why the primary operationalization of the bioethical principle of respect for patient autonomy is the patient's right to consent. "Con-sent" literally means "with-agreement", that is, agreement with one of the treatment plans suggested by the health care provider. So when it is said that respect for patient autonomy obligates the dentist to fulfill the patient's choice, that obligation is limited to so-called medically indicated treatments agreed-to by the patient.

Hence, we find the American College of Dentists (ACD) in its *Core Values & Aspirational Code of Ethics* under the header "autonomy" remind dentists that "patients have the right to determine what should be done with their own bodies. Because patients are moral entities, they are capable of autonomous decision-making. Respect for patient autonomy affirms this dynamic in the doctor-patient relationship and forms the foundation for informed consent... The patient's right to self-determination is not, however, absolute. The dentist must also weigh benefits and harms and inform the patient of contemporary standards of oral health care."[16] What the ACD calls "contemporary standards of oral health care", the ADA calls "accepted treatment". Hence, the principle of autonomy "expresses the concept that professionals have a duty to treat the patient according to the patient's desires, within the bounds of accepted treatment...".[17]

This insistence on meeting objective, scientifically determined standards of care, even if the patient is explicitly and persistently demanding something beyond those standards, underscores that patients, though fully free and rational, can still make choices that will actually harm them. Respect for patient autonomy requires health care providers to not force beneficial treatments onto the patient. Even if death is the outcome, coercion is still considered a greater violation of the dignity of the human person and undermines the possibility of moral action. But if a patient demands some intervention from the dentist that is objectively harmful to the patient, the health care provider is not obligated to facilitate the patient's self-harming choices.

THE SCOPE OF THE PRINCIPLE OF PATIENT AUTONOMY

The latter line of reasoning assumes that health care providers can in fact determine what is objectively beneficial and what is harmful to patients, such that they can recommend a (range of) treatment options from which patients can choose the one that best meets their particular needs. This is an age-old assumption. And since ancient physicians had few objectively beneficial options to offer their patients, the author of the Hippocratic Oath in our hypothetical dialogue sketched above would not have seen a need to include a specific reference to patient autonomy. But it is exactly this assumption that has come under fire in recent decades, particularly since the latter quarter of the 20th century.

The modern popularity of the principle of respect for autonomy reflects not only and maybe not primarily concerns about authorization, but today's struggle to meet the demands of beneficence and non-maleficence. For even though biomedical science has skyrocketed in the past half-a-century, and with it the ability of the health care professionals to provide effective treatments, there is ever more doubt that health care professionals can know what is in the best interest of an individual patient. One of the dominant assumptions in modern bioethics is that the health care professional cannot know the preferences, interests and values of an individual patient, unless the patient makes those known. So the only way to fulfill the principles of beneficence and non-maleficence is to do what the patient requests. It seems, then, that the principles of beneficence and non-maleficence have become subcategories of the principle of autonomy.

We can see this shift most dramatically in debates about the legalization of physician assisted suicide and euthanasia: Even death, traditionally considered the greatest harm that health care providers should strive to prevent and fight against, can become a benefit that should be brought about by physicians when and because the patient wants it. Similar considerations propel the field of reproductive medicine, facilitate the sale of blood, sperm, eggs and other tissues, and justify direct-to-consumer advertising of prescription drugs. It is employed by commercial companies to persuade people to undergo genome scans. And in dentistry, it facilitates the merger of interventions aimed at improving health and those aimed at improving beauty.

For sure, it has long been acknowledged that biomedical science can only determine what is beneficial or harmful for categories of patients who share a particular characteristic. Dental science – by definition – only yields generic knowledge that is statistically probable. Dental science cannot, in and of itself, tell the dentist what will benefit *this unique* patient. So to really do good, the dentist must – as pointed out by the FDI – encourage the patient to participate in the treatment planning. This participation occurs when the dentist takes the patient's history; when the dentist ascertains the patient's concerns, wishes and expectations; when the dentist uses empathy to learn more about the patient as a person, particularly if the patient is non-communicative; and when the dentist carefully observes the patient to determine the impact of various interventions. All of this has traditionally been understood not as a matter of respecting patient autonomy but as acting beneficently.

If, on the other hand, the definition of the patient's good is purely subjective and hence beneficence is a matter of respecting patient autonomy, it becomes very difficult to draw lines between a root canal, the placement of esthetic veneers, and a person's attempt to change his appearance into that of a lizard. The dentist then becomes a technician, who can determine which of the client's wishes can be effectively realized using dental techniques, but who cannot judge whether the outcome is beneficial or harmful to the patient.

We have seen that the ADA, while listing patient autonomy as the first of five principles, has subsumed neither beneficence nor non-maleficence under autonomy; they remain independent principles in the ADA's *Code of Ethics*. But on closer inspection it appears difficult to distinguish between autonomy and beneficence. The only difference seems to be that autonomy is defined as "abiding by patients' choices while also meeting the standard of care," while in beneficence, the order is reversed: "meeting the standard of care while also abiding by patients' choices" (Table 2).

A subsumption of beneficence and non-maleficence under patient autonomy negates the clinician's ability to reach a clinical judgment about the care of an individual patient and as such goes against a 2500 year-old tradition of understanding the nature of medicine as both a science and an art. But it not only underestimates the health care professional's ability to care for individual patients; it also overestimates the ability of the individual patient to determine what is in his/her best interests. It assumes that patients can easily determine what will medically benefit or harm them as long as they are adequately informed. Moreover, it assumes that patients want to be in charge of their own health care. The Dutch Patient Federation has even adopted as its main motto "the patient behind the wheel" (De patient aan het stuur), while also using the metaphor of patients directing their own care in the same way a movie director directs the making of a film.[18]

Table 2. ADA code of ethics

American Dental Association – Code of Ethics
Section 1 - PATIENT AUTONOMY This principle expresses the concept that professionals have a duty to treat the patient according to the patient's desires, within the bounds of accepted treatment, ...
Section 3 - BENEFICENCE ...The most important aspect of this obligation is the competent and timely delivery of dental care within the bounds of clinical circumstances presented by the patient, with due consideration being given to the needs, desires and values of the patient.

Now there is no question that many, maybe most patients, want to be partners in their care planning; they want truly beneficial care, that is, care that meets their specific and unique needs and interests. But to many patients, exercising their autonomy is not a cherished right but a heavy burden, and hence they frequently will ask "What would you do doc?" This burden becomes even more daunting when family members are expected to make difficult health care decisions on behalf of incompetent family members, such as minor children or parents with Alzheimer's dementia. Conversely, when a maxillofacial surgical team tells the parents of a child with Down syndrome, "*We* have decided not to attempt surgery to 'normalize' your kid's appearance," they thereby take onto their own shoulders part of the decision-making burden, even if the parents themselves had previously expressed hesitance to give-in to social pressures and submit their child to this purely esthetic operation.

Patients should not expect the health care provider to respect their autonomy, while also wanting the health care provider to shoulder the full responsibility for the decisions made. This is why the UNESCO in its *Universal Declaration on Bioethics and Human Rights* combines the two into one: "Article 5 - Autonomy and individual responsibility: The autonomy of persons to make decisions, while taking responsibility for those decisions and respecting the autonomy of others, is to be respected ..." But health care providers should not, under the guise of respect for patient autonomy, turn autonomy from a patient's right into a patient's duty. In is therefore troublesome that in American care facilities, patients must sign consent forms even before they are being seen by a health care provider; that consent forms are increasingly designed as risk management documents to protect the care provider against complaints or malpractice suits; and that the verb "to consent" is now changing from an active verb ("Mr. P. consents to the treatment") into a passive verb ("Mr. P. has been consented").

RECAPITULATION

Our cursory review of the history of the bioethical principle of respect for patient autonomy has revealed its origins to be primarily political and reflecting concerns about power differences unduly restricting the freedom of the more vulnerable individuals in human relationships. In the words of the American Supreme Court justice Brandeis, "The makers of our Constitution ... conferred the right to be let alone" (Olmstead v. United States, 277 U.S. 438 (1928)). Of course, patients do not visit dentists because they want to be left alone. And from that perspective, it makes little sense to list autonomy as a normative principle guiding health care, let alone as the principal such principle. There are, however, other important reasons to respect patient autonomy, specifically the intrinsic dignity of the human person, the inviolability of the patient's body and mind, and the importance of individual freedom for any moral course of action.

The health care provider has a duty to act beneficently and first and foremost not to harm the patient. But that duty only takes effect once the patient has authorized the health care provider to treat. The health care provider does not have a duty (nor a right) to treat independently of the patient's own duty to be a good care taker of his/her life and health. By consenting to treatment, the patient both authorizes the dentist to treat him/her, and assumes joint responsibility for that treatment and its outcomes. Consent, understood as authorization, thus becomes a necessary condition of any dental intervention.

However, the principle of respect for patient autonomy should not be "exploded" to comprise a variety of normative aspects that are not properly a matter of autonomy. Most notably, respect of patient autonomy should not become an excuse for dentistry to evade the difficult scientific and clinical challenge of determining the best interests of individual patients. Dental science is always only statistically true. To determine a treatment plan that will benefit a unique patient here and now necessitates active involvement of and participation by the patient. But such participation should not be understood as an exercise of patient autonomy. Instead, it is the operationalization of the ancient bioethical principles of beneficence and non-maleficence. It is in the ongoing dialogue between health care provider and patient, that the patient's best interests can be determined and translated into a scientifically supported and effective treatment plan. Patient autonomy only takes center-stage towards the very end of this constructive process when the patient authorizes the dentist to implement the mutually agreed-upon treatment plan.

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NOTES

* The UNESCO Declaration does not subsume the duty to maintain confidentiality under the principle of autonomy but dedicates a separate principle to it. There are many other reasons to question the ADA's subsumption. Historically, it is questionable since the duty to maintain confidentiality can be found in documents as ancient as the Hippocratic Oath, whereas the duty to respect patient autonomy is a 20th century addition to such normative documents. More importantly, the right to autonomy is a negative right or liberty right, as explained later. It requires others, specifically health care providers, *not* to do something, that is *not* to treat or otherwise intervene in the patient's life, body, and mind. In contrast, the duty to maintain confidentiality requires dentists to undertake a variety of steps to assure that no information about the patient can be accessed by others, such as designing the office so that nobody can eaves-drop on conversations between dentist and patient, and locking up medical records or encrypting electronic such documents.

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Review of the dental treatment backlog of people with disabilities in Europe (*)

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ABSTRACT

Aim: The present research aims at reviewing the oral health conditions and treatment needs of people with disabilities in Europe.

Methods: A comprehensive literature search was conducted using Medline and Embase with a timeframe from January 2008 until December 2017. Subsequently, a citation tracking was undertaken. Articles in English, French and Dutch were included.

Results: Forty-two articles were included. A variety of oral health problems and treatment needs was reported. More untreated carious lesions, less restorations, a higher number of extractions and less prosthetic rehabilitations were seen in people with disabilities compared with other individuals without disabilities. The oral hygiene level and the periodontal conditions were poor. Moreover, a higher risk of dental trauma, orthodontic problems and tooth wear were reported.

Discussion: Different determinants contribute to the oral health condition and treatment needs of people with disabilities. These determinants can be inherent in persons with a disability (biological factors), their lifestyle, the environment or the organization of oral health care. A treatment backlog was a common finding in people with disabilities. However, results need to be interpreted with caution because of the variety of people with disabilities included in this literature review. Proposed solutions can be put at the level of daily oral care, through oral health promotion programs and the creation of a supportive environment, but also at the level of dental attendance, facilitating the access to oral health care services and focusing the training of dental students and dentists.

Conclusion: This comprehensive review clearly shows a dental treatment backlog in people with disabilities. Solutions require efforts from the caregivers and dental professionals.

INTRODUCTION

Oral health is an integral part of the global health and is essential to the people's wellbeing.[1-3] In order to develop strategies and interventions to improve oral health in the Flemish part of Belgium, the Flemish Government made an agreement with the Flemish dentist associations and the Ghent University and KU Leuven departments of oral health sciences. The aim of this agreement was to develop preventive strategies, for the Flemish population in general on one hand, and for different groups of vulnerable individuals on the other.

In Flanders, oral health promotion strategies are currently being developed targeting people with low socioeconomic status, frail older persons and people with disabilities. The current review focuses on the latter. In 2012 about 15 percent of the world population had a disability, compared to a similar 16 percent of the Belgian 15-64 population.[4,5]
In order to align Flemish preventive oral health strategies with the actual oral health needs of people with disabilities, an overview of reported oral health problems and treatment needs was prepared. The current study aims at reviewing the oral health condition and treatment needs of people with disabilities in Europe.

MATERIALS AND METHODS

Definition of people with disabilities

In analogy with a previous national pilot study that took place in Belgium in 2014, people with disabilities were defined as "people who cannot take care of their own (oral) health because of a mental, physical or medical condition, irrespective of age".[6] The current review focuses on children and adults with an intellectual or physical disability and people with autism. Since we intended to include only studies about people depending on others for their oral health, we excluded studies about people with a psychological, visual and/or hearing impairment without intellectual disability or studies including hospitalized people.

Search Strategy

A comprehensive literature search was conducted using Medline and Embase. The search queries for both databases are attached as appendix. Since only the recent situation was considered relevant, a timeframe for publication date was set from January 2008 until December 2017.
Subsequently, a selection of relevant papers based on title and abstract, and finally full-text, was undertaken. Only studies performed in Europe and published in English, French or Dutch were included to obtain information as close as possible to the situation in Flanders. Furthermore, a citation tracking via Google Scholar and the consulting of the reference lists of included articles was carried out to obtain a search as broad as possible.

RESULTS

The literature search resulted in 2735 publications in Medline and 965 publications in Embase. After the selection process, 42 studies were included. Children with myotonic dystrophy type 1 and children with disabilities had a higher DMFT (decayed, missing, and filled teeth) than children without disabilities.[7,8] However, in females with Rett syndrome and adults with Prader Willi syndrome, DMFT was lower than in the general population.[9,10] In adolescents with ADHD (Attention-Deficit/Hyperactivity Disorder) and children with disabilities more teeth decay resulted untreated[8,11], while less untreated tooth decay was detected in people with Down syndrome.[12-14] Children with Cerebral Palsy underwent more tooth extractions compared with children in general.[15] Moreover, children, adolescents and adults with a disability showed less dental restorations than the population in general.[8,9,11,15-17]
A higher plaque index was reported in both children and adults with disabilities.[7,17,18] Furthermore, in several groups, except for adults with an autism spectrum disorder, gingival health was worse in people with disabilities.[9-11,19] Studies reported signs of gingivitis in 39 to 70 percent of athletes with intellectual disabilities.[12,20-26] Moreover, in these athletes, signs of gingivitis were significantly correlated with age.[22,25,26]
Compared to the general population, edentulism was seen more often in people with intellectual disabilities.[26,27] However, prosthetic rehabilitation was found less often [27-29], with a prevalence of edentulous people without prosthetic rehabilitation ranging from 18 to 61 percent in people with an intellectual disability.[6,25-27,30]
A history of dental trauma was more frequent in several groups of children with disabilities.[31,32] Moreover, in children with disabilities the consequences of dental trauma remained untreated more often than in children without disabilities.[33] A higher prevalence of tooth wear related to bruxism was noted in children with Down syndrome and females with Rett syndrome.[9,13]
When considering orthodontic characteristics, severe orofacial morphological problems were seen more often in children and adolescents with disabilities.[33] Several subgroups of people with disabilities had a larger number of individuals with an anterior open bite.[9,17,34] In addition, adults with Prader Willi syndrome and children with Down

syndrome suffered from hypodontia more often.[10,35]

DISCUSSION

The aim of this review was to describe the oral health condition and treatment needs of people with disabilities in Europe. Common findings were a higher frequency of diseases, diseases at a more severe stage and a dental treatment backlog in both children and adults with disabilities.

Explanatory Factors

Many determinants contribute to the oral health and treatment needs. According to the model proposed by Lalonde (1974), they can be categorized in biological factors, lifestyle, environment and the organization of the oral health care services.[36]

Biological Factors

The biological factors are characteristics of a person, which are hard to control or change.[36] Cognitive factors influence oral hygiene habits of people with intellectual disabilities (e.g. they do not know why and how to brush their teeth, they forget tooth brushing).[37] Moreover, physical factors, like a lack of coordination, sensory problems or abnormal craniofacial and oral muscle tone, seem to make tooth brushing more challenging.[37] Furthermore, oral health maintenance could be perceived not as a priority issue, because other medical or social issues are considered more important.[37,38]

Antipsychotic, anticonvulsant and anxiolytic medication are known to trigger side effects (e.g. xerostomia, gastroesophageal reflux disease, tongue oedema, tongue spasms, bruxism or gingival hyperplasia).[39,40] Moreover, xerostomia and gastroesophageal reflux disease increase the risk of tooth decay, periodontal diseases and erosion of the tooth surfaces.[39] In addition, gastrointestinal problems influence oral health. Idaira et al. (2008) detected significantly more carious lesions in people with disabilities who ruminate.[41] In people fed by tube, less carious lesions but more calculus were described.[41,42]

Lifestyle

Lifestyle factors can be influenced more easily than biological factors. In children with Down syndrome, compared to children without Down syndrome, no differences in food habits were described by Areias et al. (2011).[13] Significantly less food moments were reported in adults with autism spectrum disorders, children with disabilities and adolescents with disabilities.[19,43] Furthermore, Hennequin et al. (2008) described a lower consumption of sugar drinks in children and adolescents with disabilities.[33]

Considering tooth brushing, 74 to 96 percent of athletes with an intellectual disability reported to brush their teeth at least once a day.[12,21-23,25] However, compared to the population in general, less tooth brushing moments were seen in adults with autism spectrum disorders, children with disabilities and adults with disabilities.[19,43]

Environment

Parents and caregivers are most often the oral care providers to people with disabilities. However, Klingberg and Hallberg (2012) described that, in the context of the oral cavity, parents tended to focus more on communication and feeding problems than on tooth decay and periodontal problems. They also felt unsure about delivering oral care to their child with a disability.[38]

Similarly, Chadwick et al. (2018) described that caregivers felt uncertain when carrying out oral care (e.g. when gums bleed).[37] Moreover, they could face uncooperative behaviours, like hitting or biting [37,44,45], which might create barriers to provide oral care. These barriers partly explain why, despite the necessity of help and assistance in tooth brushing, help to people with disabilities is not always provided when needed.[20,46-48]

Organization of oral health care services

The final explanatory factor lies in the management of oral health care services. In addition to daily oral care, dental visits contribute to obtain and maintain oral health. However, people with disabilities face barriers to visit the dentist (**Table 1**). The other way round, barriers and concerns about dental treatment of people with disabilities are also mentioned by dentists (**Table 2**).

In the Greek study of Gizani et al. (2014), more than 90 percent of the dentists mentioned that dental treatment of people with disabilities was difficult but rewarding.[49] Nevertheless, Marks et al. (2012) described that 86 percent of the Flemish and Dutch dentists had emotional concerns when they treated people with disabilities.[50]

Treatment options in people with disabilities can be limited, which has been demonstrated in literature. Children, adolescents and adults with a disability receive less dental restorations than the population in general.[8,9,11,15-17,51,52] Dziwak et al. (2017) reported less use of dental sealants in German children with disabilities.[8]

Table 1. Barriers to professional dental care mentioned by people with disabilities

Accessibility and architecture[29,64,75,76]
Costs of treatment and/or lack of reimbursement[75-77]
Distance and difficulties with transport[72,75]
Fear[29,76,78]
Little availability dentists[29,64,72,75,76]
Long waiting list[64,72,75]
Missing the appointment[19]
No perceived need (e.g. no pain)[76]
Physical disability or non-cooperation[76,79]
Uncertain treatment is possible[75]

Table 2. Barriers to professional dental care mentioned by dentists

Accessibility and equipment[44,49,73]
Concerns about durability of treatment[73]
Concerns about medical history[73]
Extra staff needed[73]
Extra time needed[80]
Lack of communication[38,44,49,73]
Lack of experience[38]
Lack of financial support[44,49,73]
Lack of knowledge and training[38,44,49]
Lack of treatment options[44,73]
Non-cooperation[33,38,44,46,80]

Importantly, Bissar et al. (2010) showed a lower DMFT in young German athletes with an intellectual disability when they had at least one dental sealant.[20] In Belgium, less dental radiographs, less orthodontic evaluation and treatments, and less endodontic treatments were registered in people with disabilities. Consequently, more emergency treatments were seen in both children and adults with disabilities compared to the general population.[51,52]

Limitations

The current results need to be interpreted with caution. Due to a broad definition of people with disabilities, a variety of disabilities and impairments were included in this literature review. Furthermore, the studied populations were mostly small and did not represent all age groups. Moreover, since a variety of measuring tools was used, comparison of the results from different studies was challenging.
Despite these limitations, this review illustrates the dental treatment needs and treatment backlog of people with disabilities in Europe. In addition, the findings are confirmed in literature from outside Europe.[53-61]

PROPOSED SOLUTIONS

Daily oral care

To improve the oral health of people with disabilities, both the daily oral care and the professional dental care should be ameliorated. Oral health promotion interventions, targeting people with disabilities, their family and caregivers, are indispensable to improve daily oral care. Furthermore, a supportive environment is essential to convert acquired knowledge and skills into good practices and attitudes.[37,53-56,58,62-65] Oral hygiene should be individualized by the adaptation of materials (e.g. choice of toothbrush or toothpaste) and tooth brushing should be incorporated in the daily routine of the person with a disability.[37,66,67] A customized use of fluoride can help to achieve and maintain the desired oral health level.

Dental visit

Dentists should be encouraged to treat people with disabilities. Therefore, (general) dentists should be trained to make them feel more comfortable in treating people with disabilities. Both undergraduate and specialized postgraduate courses are necessary, including education on the following issues: impact of disabilities on oral health; barriers for people with disabilities (for daily and professional oral and dental care); clinical decision making and treatment options; communication with people with disabilities.[49,50,68-73] General dentists should be able to treat people with mild to moderate intellectual disabilities, whereas specialist care should be reserved to more severe cases.

Dentists should receive more financial support when treating people with disabilities and they should be encouraged to make their offices more accessible to disabled people. Finally, a network of dentists should be established, including referral pathways from primary to specialist care. The network should be based on a foundation of general dentists [70,72], and people with disabilities should be informed about this network and how it works.

Ethical dilemma?

The described treatment backlog in people with disabilities can clearly be considered unethical. There is a need for solutions and people with disabilities need support and assistance in maintaining their oral health. However, providing this support and assistance might cross the borders of respecting the patient's autonomy. After all, the possibility of making choices should not be denied to people with disabilities.[74]

Therefore, one should strive for a balance between the theoretically known needs and those perceived by people with disabilities. People with disabilities can be guided in making healthy choices, for example by creating a supportive environment. Moreover, people with disabilities can participate in the decision making process of implementing oral health strategies, which empowers their autonomy. Ultimately, this will align oral health interventions with their needs in order to make the interventions more durable and sustainable.

CONCLUSION

This comprehensive review clearly demonstrates a dental treatment backlog in people with disabilities. Efforts from caregivers and dental professionals are required, based on appropriate training and education.

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APPENDIX

Medline (via PubMed – "all fields"):

("Autism" OR "Behavior disorder" OR "Cognitive dysfunction" OR "Cognitive dysfunction"[MeSH Terms] OR "Dental care for disabled" OR "Dental care for disabled"[MeSH Terms] OR "Disability" OR "Disabled person" OR "Disabled persons"[MeSH Terms] OR "Learning disorder" OR "Mental deficiency" OR "Mental infantilism" OR "Neurodevelopmental disorders" OR "Neurodevelopmental disorders"[MeSH Terms] OR "Thought disorder") AND ("Dental health behavior" OR "Dental health care" OR "Dental health education" OR "Dental health motivation" OR "Dental health promotion" OR "Dental health services" OR "Dental health services"[MeSH Terms] OR "Dental prevention" OR ("Health behavior" AND ("Dentistry" OR "Dental health")) OR (("Health behavior" OR "Health behavior"[MeSH Terms]) AND (("Dentistry" OR "Dentistry"[MeSH Terms]) OR ("Oral health" OR "Oral health"[MeSH Terms]))) OR ("Health promotion" AND ("Dentistry" OR "Dental health")) OR (("Health promotion" OR "Health promotion"[MeSH Terms]) AND (("Dentistry" OR "Dentistry"[MeSH Terms]) OR ("Oral health" OR "Oral health"[MeSH Terms]))) OR "Health education, dental" OR "Health education, dental"[MeSH Terms] OR "Oral health behavior" OR "Oral health care" OR "Oral health education" OR "Oral health motivation" OR "Oral health promotion" OR "Oral health services" OR "Mouth hygiene" OR ("Motivation" AND ("Dentistry" OR "Dental health")) OR (("Motivation" OR "Motivation"[MeSH Terms]) AND (("Dentistry" OR "Dentistry"[MeSH Terms]) OR ("Oral health" OR "Oral health"[MeSH Terms]))) OR "Preventive dentistry" OR "Preventive dentistry"[MeSH Terms] OR "Public health dentistry" OR "Public health dentistry"[MeSH Terms] OR ("Public health service" AND ("Dentistry" OR "Dental health")) OR "Dental determinants" OR "Dental disease assessment" OR "Dental health" OR "Dental health literacy" OR "Dental health surveys" OR "Dental health surveys"[MeSH Terms] OR "Determinants, dental" OR "Determinants, oral" OR ("Epidemiology" AND ("Dentistry" OR "Dental health")) OR (("Epidemiology" OR "Epidemiology"[MeSH Terms]) AND (("Dentistry" OR "Dentistry"[MeSH Terms]) OR ("Oral health" OR "Oral health"[MeSH Terms]))) OR "Mouth disease" OR "Need for dental care" OR "Need for oral care" OR "Oral health determinants" OR "Oral health" OR "Oral health"[MeSH Terms] OR "Oral health literacy" OR "Stomatognathic Diseases" OR "Stomatognathic Diseases"[MeSH Terms])

Embase ("all fields"):

('Autism' OR 'Behavior disorder' OR 'Disability' OR 'Disabled person' OR 'Learning disorder' OR 'Mental deficiency' OR 'Mental infantilism' OR 'Thought disorder') AND ('Dental health behavior' OR 'Dental health care' OR 'Dental health education' OR 'Dental health motivation' OR 'Dental health promotion' OR 'Dental prevention' OR ('Health behavior' AND ('Dentistry' OR 'Dental health')) OR ('Health promotion' AND ('Dentistry' OR 'Dental health')) OR 'Oral health behavior' OR 'Oral health care' OR 'Oral health education' OR 'Oral health motivation' OR 'Oral health promotion' OR 'Oral health services' OR 'Mouth hygiene' OR ('Motivation' AND ('Dentistry' OR 'Dental health')) OR ('Public health service' AND ('Dentistry' OR 'Dental health')) OR 'Dental determinants' OR 'Dental disease assessment' OR 'Dental health' OR 'Dental health literacy' OR 'Determinants, dental' OR 'Determinants, oral' OR ('Epidemiology' AND ('Dentistry' OR 'Dental health')) OR 'Mouth disease' OR 'Need for dental care' OR 'Need for oral care' OR 'Oral health determinants' OR 'Oral health literacy')