Dental pattern diversity in a military population and its usefulness for assessing the degree of certainty in dental identification

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A R T I C L E   I N F O

A B S T R A C T

In forensic dentistry, the analysis of dental diversity forms the basis of probability calculations in dental identification. The present study aimed to contribute to the knowledge of dental diversity in a Spanish military population (considering isolated teeth, sets of different numbers of teeth, and combinations of teeth of forensic interest) and its implications for dental identification. A further aim was to compare the performance of three coding systems (detailed, generic, and binary) to assess dental pattern diversity. Dental diversity of a representative sample of the Spanish military population (3920 individuals aged between 18 and 55 years) was calculated according to a genetic (mitochondrial DNA) model in which diversity was defined as the likelihood that two randomly selected individuals in a sample would exhibit different patterns. By performing all pairwise comparisons of dental patterns in the dataset, the total number of matches was generated, and the diversity of dental patterns was then derived. First and third molars were the teeth that showed the highest levels of diversity, and a high diversity value (> 0.99) was obtained with only 5 teeth (*16*, *36*, *38*, *46*, and *48*) when detailed coding was used. In addition, dental diversity in the full dentition and posterior teeth exceeded the threshold of 0.99 in all three coding systems. Although a very high diversity value (≥0.999) was only achieved with detailed coding, it should be noted that the generic coding system requires less time and skill to use, and can also provide high diversity values. Our findings show that further efforts should be made to establish large, periodically updated dental datasets of different populations in order to assess dental pattern diversity (without excluding third molars) based on empirical comparison, and to substantiate the certainty of dental identification.

1. Introduction

Antemortem and postmortem dental records – including photographs, radiographs, dental charts and dental casts – are commonly compared for purposes of human identification in forensic dentistry [1,2]. According to the International Crime Police Organization (INTERPOL), the comparison of antemortem and postmortem dental identifiers constitutes a primary means of personal identification [3]. It has been accepted that a positive identification is established when comparisons disclose significant overlap and no unexplainable differences [4]. However, controversy persists regarding the results of qualitative or quantitative assessments of forensic examinations. In recent years many authors have advocated

for a paradigm shift in forensic sciences, from a model rooted in human perception and subjective judgement toward more rigorous methods based on data, quantitative measurements, and statistical models [5,6]. In this regard the degree of individuality in human dentition can be quantified from two different perspectives: separately evaluating each dental feature (morphological, pathological or therapeutic) that can be considered rare or extraordinary, or assessing particular combinations of characteristics of the dentition to discern distinctive dental patterns [7]. Therefore, the study of dental diversity constitutes an area of interest in forensic dental identification.

It has been stated that empirical observation of large reference datasets is the best technique to assess dental diversity in a population as a whole [8]. Several studies based on results from national oral health surveys have reported the diversity of dental patterns in different populations, in efforts to determine the discriminatory potential of the dentition [7–10]. These studies calculated dental

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J. Martínez-Chicón, A.B. Márquez-Ruiz, L. González-Herrera et al.

Forensic Science International 345 (2023) 111609

diversity according to a genetic (mitochondrial DNA) model in which a statistical strategy defined diversity as the likelihood that two randomly selected individuals in a sample would exhibit different patterns. By performing all pairwise comparisons of dental patterns in large datasets, overall frequencies of matches can be generated, and the overall diversity of dental patterns can then be derived. The results of these studies have been statistically compared to those from mitochondrial DNA sequences, which yield values on the order of trillions of possible combinations [8–10]. However, despite the fact that dental variants are at least as abundant as the number of mitochondrial DNA variants [8], it should not be forgotten that dental patterns are less stable than mitochondrial DNA sequences, since the former depend on dental health status, which is closely related to age and birth cohort [9].

In order to assess the diversity of dental patterns, dental characteristics recorded in dental charts need to be converted into dental codes. Although several coding systems with different levels of detail have been used [7–10], it is important to determine which coding system can offer the most rapid, accurate, and useful results for quantifying the strength of a match between dental patterns.

Clearly, human identification is of particular importance for the military population. Because they are often exposed to situations of extreme risk, military personnel are more likely to require corpse identification compared to the civilian population [11,12]. Consequently, specific protocols have been proposed for the technical procedures used to identify victims belonging to the armed forces [13,14], and the study of dental diversity in military populations has consequently attracted research interest [7,8,15–17]. An important contribution from these studies was the OdontoSearch computer program [7], which compares an individual's pattern of missing, filled, and unrestored teeth to a representative sample of the U.S. civilian and military populations, and provides an objective means of quantifying the relative frequency of specific dental patterns in the general population.

In light of the shortcomings of current methods, the present study was designed to analyze the diversity of dental patterns in a representative sample of the Spanish military population, by recording data from dental charts with three coding systems of different levels of detail (called here *detailed*, *generic*, and *binary*). A primary aim was to contribute to the knowledge of dental diversity in this population, considering isolated teeth, sets of different numbers of teeth, and combinations of teeth of forensic interest in addition to analyzing the influence of age and sex. A further aim was to compare the performance of different coding systems used to assess dental pattern diversity. Our findings have potential applications to assessments of the degree of certainty of dental identification.

2. Material and methods

2.1. Sample collection

Before international missions (and routinely since 2015), Spanish military personnel undergo medical and dental examinations in the course of which an anthropometric form and photograph, a biological sample (blood) for DNA investigation, and a complete dental record (dental chart) are routinely collected in a health identification file (*Ficha de Identificación Sanitaria*, FISAN) [18] for possible subsequent identification. In the present study, dental data were retrospectively collected from the FISAN filed between 2006 and 2008 in the Health Services of different military centers of Spain. The sample consisted of dental data from 3920 individuals [3437 men (87.7%) and 483 women (12.3%)] aged between 18 (minimum age for enlisting in the Spanish armed forces) and 55 years (mean age: 28.10 ± 7.68 years), and was representative of the study population.

Dental records were introduced in the Dental Encoder© database [19], which was previously developed by the authors to facilitate the transcription of dental information and its subsequent statistical analysis. Dental Encoder© uses the Forensic Dental Symbols© font, a universal graphic dental system that facilitates dental data entering, coding, management and storage [19]. Dental Encoder© establishes a direct relationship between each clinical characteristic and its corresponding dental symbol, so that when the characteristic is selected in the form, the symbol is automatically stored in the database. Forensic Dental Symbols© is designed such that clinical characteristics behave like alphabetic characters, thereby enabling their complete integration into any computer application that processes text, such as spreadsheets. To standardize the methodology used for data management, the same official dentist (Dr. J.M.-C.) carried out data transcription and subsequent computerization. The data were collected and processed with mandatory authorization from the Ministry of Defense of Spain, in compliance with the Spanish Law on the Protection of Personal Data and with the international recommendations of the World Medical Association for clinical research as set forth in the Declaration of Helsinki.

2.2. Dental coding systems

Dental data were recorded from dental charts using three coding systems, adapted from other authors [7–10] and characterized by different levels of detail in which the different clinical characteristics were coded. The first system, called *detailed*, consisted of 105 dental categories; it considered tooth surfaces affected by caries or restorations, noted the materials used, and collected other specific clinical characteristics. The second system, called *generic*, grouped similar clinical characteristics into four dental categories (*unrestored*, *restored*, *missing* and *crown*) in order to analyze the results from more limited data. The third system, called *binary*, consisted of the numerical values 0 and 1. This system, intended to group together all similar clinical characteristics, coded the presence of a restoration or crown or the absence of a tooth as *1*, and a healthy or unrestored tooth as *0*. The dental clinical characteristics represented by each type of coding, together with their corresponding dental symbols, are listed in Fig. 1.

2.3. Data analysis

The statistical method for diversity analysis closely followed that of earlier work [8–10] in which total diversity was calculated as: $\sum_{i>j}^{\delta ij}/\{[N(N-1)]/2\}$, where $\delta_{ij}= 1$ when individuals i and j have different patterns and 0 when they share the same pattern. Briefly, pairwise comparisons were done in the dataset and the total number of pattern matches ($i=j$) was determined. The total number of pairwise comparisons (i.e. the possible pairs that can be established among all N individuals in the sample) was calculated as $[N(N-1)]/2$. Random match probabilities were estimated as the ratio of the number of pattern matches found during pairwise comparisons (as opposed to mismatches) to the total number of pairwise comparisons. Diversity was calculated as the difference between the random match probability estimate and 1. Therefore, diversity values ranged from 0 to 1: a value of 1 indicated that all patterns present within the data were distinct, and a value of 0 indicated that all patterns were the same. Statistical analysis was done with SPSS version 26.0 software (IBM Corporation, Armonk, NY, USA). In order to complete the analysis of dental pattern diversity, the influence of age and sex was assessed by applying the previous formulas separately to three age groups (18–25, 26–35 and 36–55 years), and to men and women. Arlequin 3.5 software for population genetics data analysis [20] was used for this purpose.

J. Martínez-Chicón, A.B. Márquez-Ruiz, L. González-Herrera et al.

Forensic Science International 345 (2023) 111609

Fig. 1. Correspondences among different dental clinical characteristics and their corresponding dental symbols (Forensic Dental Symbols© font type [19]) in each type of coding.
[a]Detailed coding required a different symbol depending on the tooth surface(s) affected by caries or restoration.

3. Results

In accordance with the proposed methodology, we analyzed the diversity of dental clinical characteristics individually in each tooth in order to find the teeth with the greatest variability. As shown in Table 1, the highest diversity values were obtained with the detailed coding system. In contrast, the lowest diversity rates were observed when binary coding was used. Mandibular first and third molars were the teeth that showed the highest diversity values when a single tooth was considered with the detailed coding method (0.7797–0.8115). With generic coding, the teeth that yielded the greatest diversity were the maxillary and mandibular first molars

(0.5954–0.6513), whereas with binary coding, maxillary first and third molars presented the highest levels of diversity (0.4981–0.4997).

Another aim of this study was to determine how many teeth (and which of them) were necessary to obtain a high diversity value (i.e. highly diverse patterns). For this purpose, we compared 32 combinations of decreasing numbers of teeth (Table 2). For each coding system, the analysis started with the full dentition (32 teeth). Then the tooth that individually presented the lowest diversity index in each coding system (Table 1) was excluded. The order of exclusion in successive iterations coincided to a large extent across all three coding systems. The highest dental diversity indexes were obtained

Table 1
Diversity values for each tooth type according to the type of coding.

Tooth[a]	Detailed coding Diversity	Generic coding Diversity	Binary coding Diversity	Tooth[a]	Detailed coding Diversity	Generic coding Diversity	Binary coding Diversity
11	0.2581	0.1906	0.1845	21	0.2667	0.2001	0.1934
12	0.2055	0.1647	0.1597	22	0.2090	0.1691	0.1639
13	0.1153	0.0952	0.0936	23	0.1066	0.0909	0.0895
14	0.4186	0.3532	0.3292	24	0.4067	0.3434	0.3207
15	0.4379	0.3714	0.3443	25	0.4283	0.3630	0.3374
16	0.7640	0.5960	0.4997	26	0.7497	0.5954	0.4988
17	0.5726	0.4442	0.4215	27	0.5655	0.4457	0.4211
18	0.6893	0.5342	0.4994	28	0.6728	0.5283	0.4981
41	0.0278	0.0203	0.0202	31	0.0314	0.0208	0.0207
42	0.0213	0.0152	0.0152	32	0.0208	0.0132	0.0132
43	0.0188	0.0152	0.0152	33	0.0193	0.0172	0.0172
44	0.1540	0.1300	0.1274	34	0.1471	0.1194	0.1172
45	0.3172	0.2752	0.2629	35	0.3175	0.2675	0.2558
46	0.8115	0.6436	0.4957	36	0.8077	0.6513	0.4945
47	0.7177	0.5480	0.4861	37	0.7183	0.5413	0.4821
48	0.7797	0.5442	0.4958	38	0.7830	0.5498	0.4977

[a] FDI notation is used for tooth numbering.

J. Martínez-Chicón, A.B. Márquez-Ruiz, L. González-Herrera et al.

Forensic Science International 345 (2023) 111609

Table 2

Diversity values of dental patterns corresponding to combinations of N teeth according to the type of coding.

Number of teeth	Detailed coding		Generic coding		Binary coding	
	New tooth excluded[a]	Diversity	New tooth excluded[a]	Diversity	New tooth excluded[a]	Diversity
32		0.9991		0.9929		0.9926
31	43	0.9991	32	0.9928	32	0.9926
30	33	0.9991	42	0.9928	42	0.9926
29	32	0.9991	43	0.9928	43	0.9926
28	42	0.9991	33	0.9928	33	0.9926
27	41	0.9990	41	0.9927	41	0.9925
26	31	0.9990	31	0.9927	31	0.9925
25	23	0.9990	23	0.9926	23	0.9924
24	13	0.9990	13	0.9923	13	0.9921
23	34	0.9990	34	0.9923	34	0.9921
22	44	0.9990	44	0.9923	44	0.9920
21	12	0.9990	12	0.9922	12	0.9919
20	22	0.9989	22	0.9921	22	0.9918
19	11	0.9989	11	0.9918	11	0.9914
18	21	0.9987	21	0.9909	21	0.9905
17	45	0.9986	35	0.9908	35	0.9902
16	35	0.9986	45	0.9906	45	0.9898
15	24	0.9986	24	0.9903	24	0.9894
14	14	0.9984	14	0.9895	14	0.9882
13	25	0.9983	25	0.9889	25	0.9870
12	15	0.9982	15	0.9883	15	0.9851
11	27	0.9981	17	0.9878	27	0.9837
10	17	0.9980	27	0.9871	17	0.9809
9	28	0.9976	28	0.9835	37	0.9781
8	18	0.9962	18	0.9745	47	0.9718
7	47	0.9957	37	0.9721	36	0.9637
6	37	0.9947	48	0.9614	46	0.9459
5	26	0.9932	47	0.9527	48	0.9262
4	16	0.9884	38	0.9062	38	0.8820
3	48	0.9773	26	0.8762	28	0.8294
2	38	0.9101	16	0.8032	26	0.7486
1	36	0.8115	46	0.6513	18	0.4997

[a] Teeth are numbered according to FDI notation. Teeth with the lowest diversity value were excluded cumulatively in successive combinations of N teeth.

with the combination comprising all 32 teeth, as expected. The first 6 teeth to be excluded due to their very low diversity were mandibular incisors and canines in all three coding systems; thus these can be considered invariable teeth. In contrast, the last 12 teeth to be excluded were molars, i.e. the teeth with the greatest variability.

Dental pattern diversity was also studied in predetermined dental combinations of clear forensic interest: full dentition, full dentition without third molars, anterior teeth, posterior teeth, maxillary teeth, mandibular teeth, right teeth, and left teeth (Table 3). Dental diversity in the full dentition exceeded the threshold of 0.99 in all three coding systems. In other words, their complementary or random match probabilities (0.09%, 0.71%, and 0.74%, with detailed, generic, and binary coding, respectively) were close to zero, which indicates that the chance of randomly selecting two individuals with the same dental pattern was very low. Regarding the other combinations, the greatest diversity was obtained with posterior teeth in all three coding systems, with values higher

than 0.99. In all three coding systems, right or left teeth yielded higher diversity indexes than maxillary or mandibular teeth. In general, right teeth were slightly more diverse than left teeth, and maxillary teeth were slightly more diverse than mandibular ones. These combinations, however, yielded values higher than 0.99 only with detailed coding; dental diversity was considerably lower with generic and binary coding (< 0.98). In the combination of anterior teeth, dental diversity was even lower than the value yielded by any molar tooth individually, and diversity according to generic (0.4003) and binary coding (0.3991) was also much lower compared to detailed coding (0.5167).

Lastly, to analyze the influence of age on dental diversity, the sample was divided into three age subgroups: young adults (18–25 years, N = 1743), middle-aged adults (26–35 years, N = 1579), and older adults (36–55 years, N = 598). The diversity values for combinations of teeth of forensic interest according to age subgroup and type of coding are summarized in Table 4. Detailed coding produced the greatest diversity in all combinations analyzed in each age group. The highest diversity values were found in the older adults subgroup. On the other hand, no significant differences were found between the diversity values obtained in men (N = 3437) and women (N = 483) for the same combinations.

Table 3

Diversity values of dental patterns corresponding to combinations of teeth of forensic interest according to the type of coding.

Forensic situation	Detailed coding Diversity	Generic coding Diversity	Binary coding Diversity
All teeth	0.9991	0.9929	0.9926
All teeth excluding third molars	0.9895	0.9655	0.9642
Anterior teeth	0.5167	0.4003	0.3991
Posterior teeth	0.9987	0.9910	0.9907
Maxillary teeth	0.9904	0.9677	0.9661
Mandibular teeth	0.9949	0.9669	0.9593
Right teeth	0.9964	0.9782	0.9758
Left teeth	0.9959	0.9779	0.9753

4. Discussion

In forensic dentistry it is essential to analyze dental pattern diversity since it forms the basis of probability calculations for forensic identification [7–9]. Although the lack of a quantitative model does not mean that identification is unreliable [21], the probability value derived from empirical comparison with a reference dataset can be used to attach a degree of certainty to a match between dental patterns in an easily interpretable manner [7]. Given that the

J. Martínez-Chicón, A.B. Márquez-Ruiz, L. González-Herrera et al.

Forensic Science International 345 (2023) 111609

Table 4
Diversity values of dental patterns corresponding to combinations of teeth of forensic interest according to age group and type of coding.

Forensic situation	Coding	18–25 years (N = 1743) Diversity	26–35 years (N = 1579) Diversity	36–55 years (N = 598) Diversity
All teeth	Detailed	0.9982	0.9993	0.9999
	Generic	0.9838	0.9960	0.9995
	Binary	0.9835	0.9957	0.9994
All teeth excluding third molars	Detailed	0.9783	0.9938	0.9986
	Generic	0.9171	0.9846	0.9973
	Binary	0.9153	0.9834	0.9967
Anterior teeth	Detailed	0.4296	0.5388	0.6837
	Generic	0.2926	0.4272	0.6072
	Binary	0.2919	0.4258	0.6038
Posterior teeth	Detailed	0.9974	0.9990	0.9998
	Generic	0.9801	0.9949	0.9992
	Binary	0.9797	0.9945	0.9984
Maxillary teeth	Detailed	0.9821	0.9932	0.9980
	Generic	0.9368	0.9785	0.9951
	Binary	0.9353	0.9764	0.9927
Mandibular teeth	Detailed	0.9904	0.9966	0.9984
	Generic	0.9370	0.9786	0.9932
	Binary	0.9321	0.9687	0.9779
Right teeth	Detailed	0.9924	0.9978	0.9994
	Generic	0.9546	0.9869	0.9970
	Binary	0.9522	0.9841	0.9939
Left teeth	Detailed	0.9920	0.9973	0.9990
	Generic	0.9551	0.9862	0.9961
	Binary	0.9529	0.9829	0.9932

N Number of cases

quantitative statistical model based on DNA was accepted as a highly effective method, it has been suggested that this approach can be extended to other forensic examinations, including dental patterns [8,9]. The present study was thus undertaken to evaluate dental pattern diversity in a representative sample of the Spanish military population.

Analyzing the diversity of each tooth individually is potentially useful for identification, because a tooth with high diversity can serve as an element of differentiation that makes it possible to establish a positive identification based on the full dentition, fragments of the maxilla, or even from the incidental finding of an isolated tooth. In our study the first and third molars were the teeth that showed the highest diversity values when a single tooth was considered (Table 1). First molars are the first permanent teeth to erupt, and like third molars, have an occlusal surface that makes them more susceptible to caries and more likely to undergo dental treatment [22]. In addition, because of their posterior location, aberrant occlusal anatomy and abnormal eruption patterns, third molars are more prone to complications such as infection, non-restorable caries lesions, or the destruction of adjacent teeth and bone [23]. On the other hand, mandibular incisors and canines showed the lowest diversity values with all three coding systems (≤0.03; Table 1). This finding can be explained by the fact that these teeth do not have an occlusal surface and are less exposed to direct trauma than maxillary anterior teeth, so they are less likely to undergo dental treatment [22,24,25]. Therefore dental pathologies and treatments do not occur randomly throughout the dentition [8], and some teeth may contribute more than others to the diversity of dental patterns.

Given the need to estimate dental pattern diversity in clear and precise terms, and since there is no prior consensus as to the most suitable values for forensic purposes, the rates of identification obtained with mitochondrial DNA analysis have been considered an excellent frame of reference [9,26]. Accordingly, to assess dental pattern diversity qualitatively we used the following classification based on ranges of quantitative values: very high, 0.9990–1.0000; high, 0.9900–0.9990; moderate, 0.9500–0.9900; low, 0.9000–0.9500; very low, < 0.9000. The diversity values obtained in

our evaluations of a single tooth (Table 1) were generally too low for single teeth alone to be considered useful in forensic practice. However, high dental diversity (≥0.99) was obtainable with only 5 teeth (*16, 36, 38, 46,* and *48*) in the detailed coding system, 15 teeth with generic coding, and 17 teeth with binary coding (Table 2). Therefore, the level of diversity detected with detailed coding in dental patterns comprising the clinical characteristics of the right maxillary first molar and mandibular first and third molars can be considered robust enough to be useful in assessing the validity of dental pattern matches for forensic identification.

Despite the suggestion that there is no need for detailed records to increase the discriminant power of comparative data [7,8,27], our results showed that very high dental diversity (≥0.999) was only possible with detailed coding, and required the inclusion of at least 21 teeth (Table 2). Although detailed coding provided the highest diversity levels in our sample, it should be noted that it requires more time to perform and can be challenging or potentially inaccurate depending on the skills of the forensic expert who recovers dental records and/or performs the coding. On the other hand, generic coding requires less time and skill, and can be highly diagnostic when sufficient dental remains are available, although as noted above it failed to yield a very high level of diversity. Binary coding is comparatively rapid, straightforward, and unambiguous, but it produced the lowest levels of diversity. Therefore, the usefulness of dental clinical characteristics for human identification is likely to be limited by the level of detail of the dental codes used to assess dental patterns.

When all 32 teeth were used for analysis in the present study, and regardless of the level of detail in recording the dental data, the level of diversity in dental patterns (Table 3) can be considered robust enough to be useful for forensic purposes, as others have proposed [7–10,25]. Moreover, the combination of posterior teeth, which comprise only 20 teeth, was only slightly less diverse than analyses based on the full dentition (Table 3). In forensic practice this combination can occur relatively frequently, e.g. when all anterior teeth are missing due to direct trauma or charring of the remains. Therefore loss of information due to the absence of anterior teeth need not result in a significant reduction in dental diversity compared to analyses of the full dentition. This trend was also found by other authors who used dental charts [7] and panoramic radiographs [25].

The combination of all 20 posterior teeth was much more diverse than the full dentition without third molars, which comprises 28 teeth (0.9987 vs. 0.9895 with detailed coding; 0.9910 vs. 0.9655 with generic coding; and 0.9907 vs. 0.9642 with binary coding). This finding shows that the absence of third molars results in a much larger decrease in dental diversity than the absence of all 12 anterior teeth. Among other combinations, we also note that teeth from the right or left side (16 teeth) and maxillary or mandibular teeth (16 teeth) also produced diversity indexes greater than the full dentition without third molars (Table 3). This result supports the large contribution of third molars to dental diversity in these combinations, since even in combinations that comprised only half of the teeth, inclusion of the third molar consistently led to higher diversity indexes. Therefore our findings suggest that dental diversity studies should not exclude third molars from analysis. For example, Adams [8] found that when third molars were excluded, total diversity was 0.9846 with detailed coding and 0.9828 with generic coding for dental patterns derived from a sample of 19422 U.S. military personnel aged between 17 and 61 years. Our results, derived from a smaller sample (N = 3920) of a similar age range (18–55 years), showed analogous levels of diversity for the full dentition without third molars, but higher diversity values when third molars were included (Table 3).

Regardless of the tooth combination considered, the highest dental diversity indexes were found in the oldest age subgroup,

whereas the lowest values were observed in the youngest subgroup (Table 4), a tendency that has also been observed by other authors [9,10]. This can be explained by the fact that the distribution of clinical characteristics changes steadily with age and tends to become increasingly diverse [28,29], thus contributing to increasing rates of dental diversity. In addition, increases in the number of remaining teeth in parallel with the average life expectancy of the population have led to growing needs for dental care – a trend that makes dental patterns more diverse and individualized with time [30]. Therefore the effects of age on oral health status compromise the stability of dental patterns within a given population in comparison to mitochondrial DNA sequences [9,21].

Comparisons of our results with earlier studies that also used dental charts [9,10] are problematic to some extent. Firstly, previous studies extracted dental data from different national oral health surveys based on the entire Spanish [9] and Brazilian [10] populations, whereas our study sample was limited to a military population. Secondly, earlier research was based on a single code to describe the clinical condition of each tooth – an approach equivalent only to the generic coding method used here. Thirdly, dental pattern diversity in earlier work was analyzed in different adult age groups, and only the 35- to 44-year-old group is comparable to the age range of our study sample (18–55 years). Lastly, earlier analyses were based on full dentition with and without third molars and partial dentitions without third molars (maxillary teeth, mandibular teeth, and posterior teeth), and they did not consider isolated teeth or sets of different numbers of teeth. Nevertheless, our diversity values for the older age group (36–55 years) with generic coding (Table 4) are similar to those reported for the Spanish young adult [9] and Brazilian adult [10] populations (35–44 years), which were consistently higher than 0.99 for full dentition with and without third molars. However, when only the upper or lower teeth were considered, diversity in our older population (> 0.99) was higher than in these earlier studies (≤0.98). Similarly, posterior teeth yielded a very high dental diversity value in our older population (0.9992), while slightly lower albeit still high diversity values were obtained (0.9915–0.9983) in the earlier study of the Spanish population [9]. This difference can probably be explained by the exclusion of third molars from the earlier analysis, given that as discussed above, this tooth contributes substantially to dental diversity. In addition, we considered a wider age range including older people, which could contribute to increasing rates of dental diversity as explained above. Regarding possible sex differences, previous work [7–10] did not address this issue and/or did not statistically analyze possible differences in dental pattern diversity between men and women. Dental pattern diversity in the present study was not affected by sex, possibly because of the low number of women ($N = 483$) in the sample compared to the number of men ($N = 3437$). Therefore, further studies are needed in order to determine possible differences between sexes and their implications for assessing dental diversity.

5. Conclusions

Our findings show that different clinical characteristics recorded in dental charts can form dental patterns that are diverse enough to help in personal identification. With all three coding systems used in this study, a high level of diversity (> 0.99) was achieved based not only on full dentition but also when only posterior teeth (including third molars) were available. A high diversity value was also obtained with only 5 teeth (*16*, *36*, *38*, *46*, and *48*) when detailed coding was used. An important consideration is that dental treatments make dental patterns more diverse and individualized with increasing age. Therefore, further efforts should be made to establish large, periodically updated dental pattern datasets in different populations, including military ones, in order to substantiate the certainty of dental identification (i.e. the likelihood that two individuals might share the same dental pattern) through empirical assessments of dental pattern diversity.

CRediT authorship contribution statement

Jesús Martínez-Chicón: Conceptualization, Data curation, Methodology, Resources, Formal analysis, Investigation. **Ana Belén Márquez-Ruiz:** Investigation, Visualization, Writing – original draft, Writing – review & editing. **Lucas González-Herrera:** Visualization, Writing – review & editing. **Juan de Dios Luna:** Conceptualization, Formal analysis, Methodology. **Aurora Valenzuela:** Conceptualization, Methodology, Supervision, Writing – review & editing.

Declarations of interest

None.

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