

# Human identification through 3D images: a comparative method based on common dental morphological traits

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Ana Catarina Silva<sup>1,2</sup>, Alexandra  
Teixeira<sup>1,2</sup>, Teresa Pinho<sup>3</sup>, Daniel  
Pérez-Mongiovi<sup>1,2</sup>

<sup>1</sup>Associate Laboratory i4HB -  
Institute for Health and Bioeconomy,  
University Institute of Health  
Sciences - CESPU, Gandra,  
Portugal. <sup>2</sup>UCIBIO - Applied  
Molecular Biosciences Unit,  
Forensics and Biomedical Sciences  
Research Laboratory, University  
Institute of Health Sciences, (1H-  
TOXRUN, IUCS-CESPU), Gandra,  
Portugal. <sup>3</sup>UNIPRO - Oral  
Pathology and Rehabilitation  
Research Unit, University Institute  
of Health Sciences (IUCS), CESPU,  
CRL, Gandra, Portugal

**Corresponding author:**  
**daniel.mongiovi@iucs.cespu.pt**

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## KEYWORDS

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## ABSTRACT

New complementary methods to aid in the rapid identification of human remains, particularly in cases involving multiple victims and heavily degraded bodies, are valued in the forensic field. In these circumstances, the properties and characteristics of teeth make them incredibly useful for human identification. Dental morphological traits, commonly studied in anthropology, exist in the population with varying frequencies, which makes them very informative. Thus, everyone has their own dental trait profile, that may manifest with greater or lesser frequency in the population. We propose a discriminative method by exclusion for the identification of individuals, based on the evaluation of dental traits, using intraoral 3D images. For this purpose, a group of 10 dental traits was chosen to obtain a personal profile in a population group of 76 individuals. Various scenarios were created to analyze different problem cases, by using matching-exclusion tables. Three individuals (problem cases) with dental trait profiles of very low (1/27703 individuals), medium (1/136 individuals), or high frequency in the population (1/42 individuals) were randomly chosen for the experiment. Using a conservative approach, the most likely candidate for positive identification was determined in eight steps for problem case 1, five steps for problem case 2, and two final candidates were identified in problem case 3, with only one achieving 100% similarity. In contrast, the less conservative approach identified the most likely candidate in four steps for case 1, three steps for case 2, and four steps for case 3. The rarest dental profile did not necessarily require fewer steps. Our work suggests that using the well-known dental morphological traits and recent 3D imaging technology could significantly improve the efficient triage and identification of victims, especially in cases of closed mass disasters.

## INTRODUCTION

Forensic identification of victims is of extreme importance, not only for humanitarian reasons but also in civil or criminal investigation cases. Identifying human remains frequently requires a multidisciplinary approach, and techniques that best adapt to the circumstances are recommended.<sup>1</sup>

Identification with an odontological approach has proven to be very effective, relatively quick, and cost-effective. Forensic odontological methods follow an evaluation process that

considers characteristics of dental morphology, the number and position of teeth, dental pathologies and treatments, and other maxillofacial identifiers.<sup>2-4</sup> Whenever possible, dental evaluation is the preferred approach for many mass disaster casualties. In such situations, a quick triage (through the biological profile) for later application of comparative techniques will lead to a shortening of the delivery time of bodies to their families.<sup>1,5,6</sup>

The search for identity through teeth begins by comparison of postmortem (PM) and antemortem (AM) records.<sup>6</sup> These include dental pictures, clinical notes, x-rays, and three-dimensional (3D) models, among others.<sup>3-6</sup> The greater the number of physiological, pathological, or therapeutic modifications, and the less frequent the morphological characteristics are in the general population, the easier the identification will be.<sup>4</sup>

Currently, computerized tomography (CT) scans and intraoral 3D images are also recorded, especially in dental clinics with more advanced equipment.<sup>7-10</sup> Although radiographs continue to be the gold standard as an imaging support for forensic identification, these new techniques are beginning to be, at the very least, a relevant complement to forensic investigation.<sup>6,9,11,12</sup>

In mass disaster events, shortening the delivery time of mortal remains is very important, but the high number of victims and the conditions found by the Disaster Victim Identification (DVI) teams on the ground can generate complex situations, and all care must be taken to avoid making mistakes.<sup>1,3,5,6,11</sup> This is why additional methods that aid in quickly triaging candidates and confirming their identification are desirable.

Ancestry (or population affinity) is one of the parameters that help reconstruct the biological profile of victims' remains through their teeth, together with the sex, age, and height estimation; this is especially important when there are no records available for comparison of AM and PM data.<sup>5,13,14</sup> This allows us to reconstruct a profile in cases of severely degraded human remains. Anthropological studies have thoroughly researched and classified dental traits that are more prevalent in certain populations.<sup>15,16</sup> For instance, Europeans are more likely to have high degrees of the Carabelli's cusp of the first upper molar, Asians and Indo-Americans often have shovel-shaped incisors, while sub-Saharan Africans have a higher prevalence of Bushman's canine.<sup>15,16</sup> However, other dental traits are

present in all populations with minor variations, including the number of cusps on lower premolars or the pattern of grooves on lower molars.<sup>17</sup> Thus, everyone has a particular profile of dental traits, which may be very common in certain individuals but rare in others.<sup>18</sup>

There are scenarios of closed mass disasters with a high number of victims, such as plane crashes, fires, or shipwrecks, in which the severely affected bodies need to be identified.<sup>5</sup> The use of intraoral scanners would allow almost instant 3D images of the victims' dentition (complete or partial) that could even be obtained on the ground with a mobile scanning station. The availability of AM intraoral 3D recordings allows for the acquisition of dental traits' profiles, which could be quickly compared with PM profiles to speed up triage, or even clearly indicate a probable identification.

In this study, we propose a new exclusion comparative method based on dental morphological traits to assist in the triage and identification of victims in closed mass disasters.

## MATERIALS AND METHODS

### *Selection of dental traits and classification*

The selection of traits was based on their varying frequencies in northern Portugal, using a study conducted on a collection of crania and mandibles approximately one century old as a reference.<sup>19</sup> A representative mixture of easily observable traits was chosen, with variable frequencies, on different types of teeth and upper and lower jaws. The ten chosen traits were: upper central incisive shoveling, upper lateral incisive interruption groove, upper canine distal accessory ridge, lower 2<sup>nd</sup> premolar cusp number, Carabelli's cusp, hypocone of the upper second molar, lower 1<sup>st</sup> molar cusp number, lower 2<sup>nd</sup> molar cusp number, lower 1<sup>st</sup> molar groove pattern, lower 2<sup>nd</sup> molar groove pattern.

Table 1 summarizes the frequencies of selected dental traits based on anthropological studies of the Northern Portuguese population.<sup>19</sup> The breakpoint indicates the extent to which the presence of the trait is considered unequivocally present; for lower grades than the breakpoint, the trait is considered absent. For some traits, there are no grades; the breakpoint consists only of the presence or absence. Each observed trait was classified based on the ASUDAS classification (Arizona State University Dental Anthropology System).<sup>16</sup>

To classify the different dental traits, two intra-observer assessments were carried out over several days for all the individuals. In case of non-

coincidence between assessments, a third final assessment was carried out.

**Table 1.** Frequencies of the chosen traits in northern Portugal after Marado and Silva.<sup>18</sup> The breakpoint indicates the grade from which the presence of the trait is considered unequivocally present.

Trait:	Marado & Silva		Breakpoint
<b>Shovel shaped upper central incisor</b>	Presence	Absence	Presence- Grade 3-6
	3.5%	96.5%	
<b>Interruption grooves in the upper lateral incisor</b>	Presence	Absence	Presence/Absence
	12.3%	87.7%	
<b>Distal accessory ridge in the upper canine</b>	Presence	Absence	Presence- Grade 2-5
	21.5%	78.5%	
<b>Number of lingual cusps of the lower second premolar</b>	2 or 3 lingual cusps	1 lingual cusp	Presence- Grade 2-9
	21.7%	78.3%	
<b>Carabelli's Cusp</b>	Presence	Absence	Presence- Grade 5-7
	12.8%	87.2%	
<b>Hypocone</b>	Presence	Absence	Presence- Grade 2-6
	49.8%	50.2%	
<b>Cusp number of the lower first molar</b>	Presence	Absence	Presence of cusp number 5
	72.2%	27.8%	
<b>Cusp number of the lower second molar</b>	Presence	Absence	Presence of cusp number 5
	12.6%	87.4%	
<b>Groove pattern of the lower first molar</b>	Y pattern	Another pattern	Y pattern
	87.8%	12.2%	
<b>Groove pattern of the lower second molar</b>	Y pattern	Another pattern	Y pattern
	83.5%	16.5%	

#### *Sample and registration of 3D images*

Intraoral images of 76 patients from the Clínica Médico Dentária de São João da Madeira, Lda., (North of Portugal) were used in this retrospective study. Informed consent for the scientific use of the data was obtained at the time of collection, and the images were subsequently pseudo-anonymized (approval from the Institutional Ethics Committee, approval statement number 19/CE-IUCS/2021).

The individuals were of both sexes, aged between 18 and 52 years, circumscribing an adult age and a provable low number of missing teeth. The inclusion criteria were individuals with permanent dentition of both sexes and from the North of Portugal. The exclusion criteria were individuals with deciduous dentition, foreign or with dental treatment that severely affects the morphology or visibility of most traits.

The 3D images were obtained using the iTero® intraoral 3D scanner from Align Technology, Inc. MeshLab software (MeshLab\_64\_fp v2023.12) and Blender software (www.blender.org) were also used to observe and analyze 3D images and to obtain two-dimensional (2D) photos.

#### *Calculation of probabilities*

The probability of an individual having a certain trait profile in the North of Portugal was calculated by multiplying the frequency ratio of each trait, shown in Table 1 of Supplementary Information, considering the data of Table 1. To simplify the method, only the left teeth were considered. For example, we consider an individual from the northern region of Portugal who matches the following profile: absence of upper central incisive shoveling, presence of upper lateral incisive interruption groove,

absence of upper canine distal accessory ridge, presence of lower 2<sup>nd</sup> premolar cusp number, presence of Carabelli's cusp, absence of hypocone of the upper second molar, presence of lower 1<sup>st</sup> molar cusp number, presence of lower 2<sup>nd</sup> molar cusp number, Y lower 1<sup>st</sup> molar groove pattern, X lower 2<sup>nd</sup> molar groove pattern. Based on the information provided, the probability of this person having the described traits would be calculated as follows:  $0.965 \times 0.123 \times 0.785 \times 0.9 \times 0.217 \times 0.217 \times 0.502 \times 0.722 \times 0.126 \times 0.835 \times 0.165 = 1.145 \times 10^{-5}$ . This is equivalent to 1 in 8,733 persons.





*Matching-exclusion comparative table and terminology used*

A matching-exclusion table was created integrating all candidates for identification and the trait profile of the problem case. The sequence analysis of the traits was ordered from a more evenly distributed (Hypocone: 49.8%

present – 50.2 % absent) to a less balanced distribution (Upper Central Incisor Shoveling: 3.5% present – 96.5 % absent) within the population.

To fill in the table, a color code is suggested to facilitate visualization, which is explained in Table 2. In each box, similarities are indicated during the analysis, but the filling stops its progression when there is no coincidence (considered “unexplainable discrepancy”). The operator did not know the reference number of the problem cases. Some factors were taken into consideration to reflect real scenarios (see Table 2). When the operator labels the trait as “explainable discrepancy” or “Insufficient evidence”, the classification continues without exclusion. This procedure is very conservative because it does not exclude the candidate when considered “Insufficient evidence”, despite the strong indications that do not point to him as the problem case.

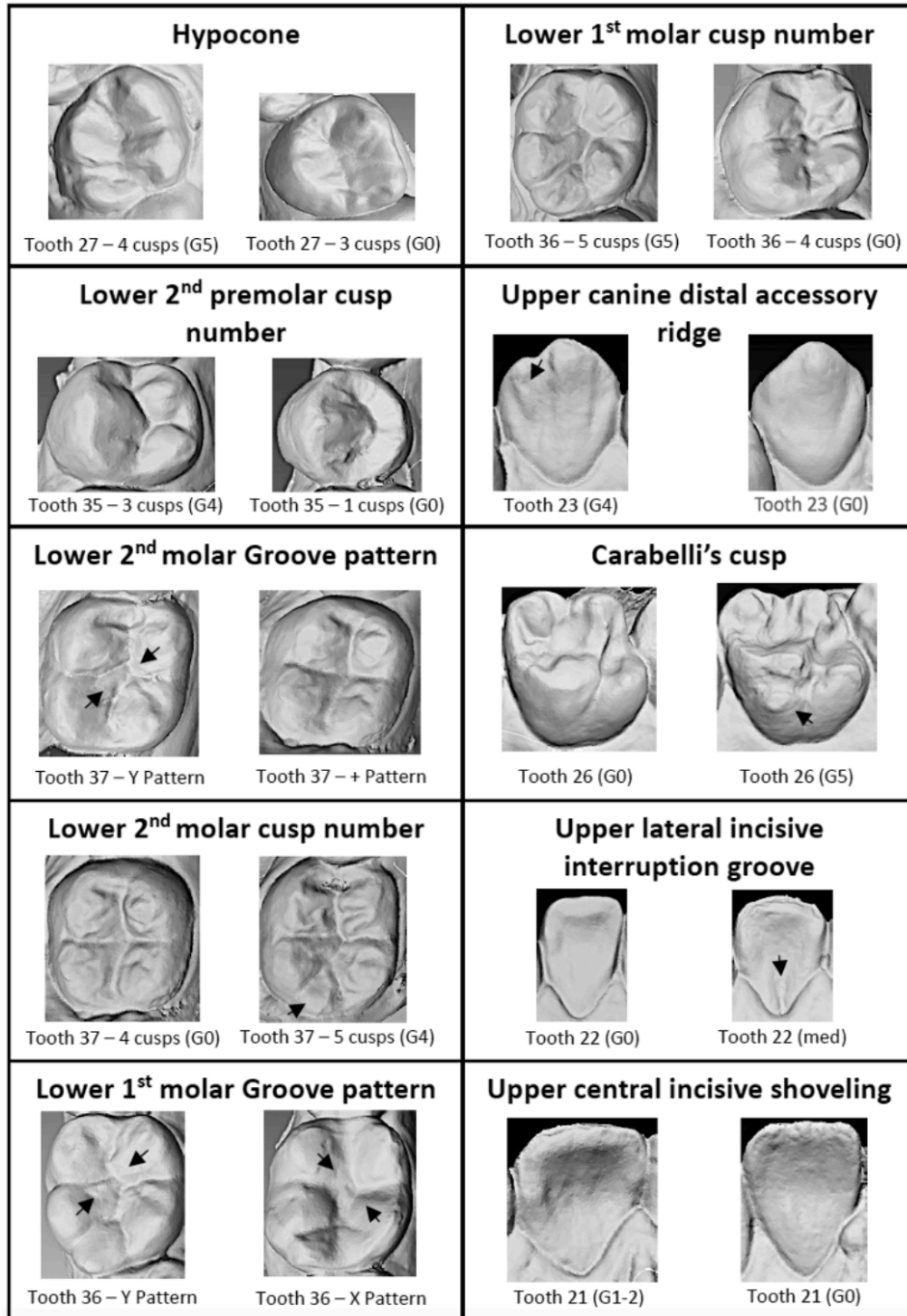
**Table 2.** Color code for the matching-exclusion comparative method, and terminology used.

Color Code	Relevance	Explanation
	<b>SIMILARITY</b>	When both classifications coincide.
	<b>EXPLAINABLE DISCREPANCY</b>	When the trait is visible in the candidates but not visible in the problem case (in a real scenario, it could correspond to a trauma at the time of the accident or dental treatment at a later date, after the provided images); or when the trait is not observable either in the candidate or in the problem case due to dental treatment; or when the difference between a present trait is up to two grades, considering ASUDAS classification (a safety inter-observer margin of two grades is applied when the trait is present).
	<b>INSUFFICIENT EVIDENCE</b>	When the trait is visible in the problem case but not in the candidates. It is more likely a case of unexplainable discrepancy due to dental treatment or missing teeth in the candidates, which is not observable in the problem case. However, the current analysis approach is very conservative, so this trait will not be considered for analysis because it cannot be compared. Also, in a real scenario, a poor image quality of a candidate's dental trait could lead to it not being considered for analysis.
	<b>UNEXPLAINABLE DISCREPANCY</b>	When the trait is present in one individual and absent in the other; when there is a difference in the trait classification of more than two grades. The discrepancies are irreconcilable. The candidate is excluded. When the colors green, yellow, or orange are assigned, the classification continues. With the red color, the classification stops, and the individual is excluded.

**RESULTS**

The analysis of 3D intraoral images allows the observation and classification of dental traits. Some images of traits chosen for this study are shown in Figure 1. The profile of the 76 individuals for the 10 dental traits used in this exercise is presented in Table 2 of the Supplementary Information.

**Figure 1.** Examples of intraoral 3D images focused on certain dental traits used in this study



Three individuals were randomly chosen as problem cases for a simulation. Profiles with different probabilities of being present in our studied population were selected (problem case 1:

1/27703 individuals; problem case 2: 1/136 individuals; problem case 3: 1/42 individuals). The dental traits profile of the problem case 1 is shown in Figure 2. The exclusion comparative

method was then applied, coming up with a single candidate (candidate 47F) who turned out to be the correct individual (Figure 3). For

problem case 2, the correct individual came up after covering half of the dental traits (candidate 59M) (Figures 4 and 5).

**Figure 2.** Dental traits profile of the problem case 1. Abbreviations of the traits are shown at the bottom lane. G: Grade, NV: Not visible, P: Present (Grade), Pa: Pattern, DT: Dental Treatment.

Hypocone	Lower 1 <sup>st</sup> Molar cusp number	Lower 2 <sup>nd</sup> Premolar cusp number	Upper canine distal accessory ridge	Lower 2 <sup>nd</sup> molar Groove pattern	Carabelli's cusp	Lower 2 <sup>nd</sup> molar cusp number	Upper lateral incisive interruption groove	Lower 1 <sup>st</sup> molar Groove pattern	Upper central incisive shoveling
G2	P(5) DT	G2	G2	Pa +	G0	P(5)	M	NV DT	G1
Hyp	L1MCN	M2MCN	UCDAR	L2MGP	Cbll	L2MCN	ULIIG	L1MGP	UCIS

**Figure 3.** Matching-exclusion table integrating all candidate individuals for identification. The references of the candidates are listed in the first column.

	Hyp	L1MCN	L2PMCN	UCDAR	L2MGP	Cbll	L2MCN	ULIIG	L1MGP	UCIS
1M	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
2F	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
3F	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
4M	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
5M	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
6F	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
7M	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
8F	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
9M	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
11F	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
12M	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
14M	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
15F	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
16M	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
17M	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
18M	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
19F	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
20M	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
21M	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
22M	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
23F	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
24F	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
25M	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
26M	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
27F	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
29F	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
30M	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
31F	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
32F	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
33M	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
35M	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
36M	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
37F	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
38F	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
39F	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
40F	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
41F	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
42F	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
43F	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
44M	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
45F	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
46M	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
47F	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
48F	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
49F	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
50M	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
52M	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
53M	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
54M	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
56F	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
57M	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
59M	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
60F	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
61M	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
62F	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
63F	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
64F	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
65M	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
66F	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
67F	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
68F	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
69M	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
71F	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
73F	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
74F	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
75M	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
76M	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
77F	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
78F	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
80M	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
81F	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
82F	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
83F	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
85M	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
86M	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green
87F	Yellow	Green	Green	Green	Green	Green	Green	Green	Green	Green

**Figure 4.** Dental traits profile of the problem case 2. Abbreviations of the traits are shown at the bottom lane. G: Grade, NV: Not visible, P: Present (Grade), A: Absent (Grade), Pa: Pattern, DT: Dental Treatment.

Hypocone	Lower 1 <sup>st</sup> Molar cusp number	Lower 2 <sup>nd</sup> Premolar cusp number	Upper canine distal accessory ridge	Lower 2 <sup>nd</sup> molar Groove pattern	Carabelli's cusp	Lower 2 <sup>nd</sup> molar cusp number	Upper lateral incisive interruption groove	Lower 1 <sup>st</sup> molar Groove pattern	Upper central incisive shoveling
G0	P(5)	G8	NV DT	Pa X	G0	A(4)	A	Pa Y	G0
Hyp	L1MCN	M2MCN	UCDAR	L2MGP	Cbll	L2MCN	ULIIG	L1MGP	UCIS

**Figure 5.** Matching-exclusion table integrating all candidate individuals for identification. The references of the candidates are listed in the first column.

	Hyp	L1MCN	L2PMC	UCDAR	L2MGP	CbII	L2MCN	ULIIG	L1MGP	UCIS
1M	Red	Yellow	Red							
2F	Red	Yellow	Red							
3F	Red	Yellow	Red							
4M	Red	Green	Red							
5M	Red	Green	Red							
6F	Red	Green	Red							
7M	Red	Green	Red							
8F	Red	Green	Red							
9M	Red	Green	Red							
11F	Red	Green	Red							
12M	Red	Green	Red							
14M	Red	Green	Red							
15F	Red	Green	Red							
16M	Red	Green	Red							
17M	Red	Green	Red							
18M	Red	Green	Red							
19F	Red	Green	Red							
20M	Red	Green	Red							
21M	Red	Green	Red							
22M	Red	Green	Red							
23F	Red	Green	Red							
24F	Red	Green	Red							
25M	Red	Green	Red							
26M	Red	Green	Red							
27F	Red	Green	Red							
29F	Red	Green	Red							
30M	Red	Green	Red							
31F	Red	Green	Red							
32F	Red	Green	Red							
33M	Red	Green	Red							
35M	Red	Green	Red	Yellow	Red					
36M	Red	Green	Red	Yellow	Red					
37F	Red	Green	Red							
38F	Red	Green	Red							
39F	Red	Green	Red							
40F	Red	Green	Red							
41F	Red	Green	Red							
42F	Red	Green	Red							
43F	Red	Green	Red							
44M	Red	Green	Red							
45F	Red	Green	Red							
46M	Red	Green	Red							
47F	Red	Green	Red							
48F	Red	Green	Red							
49F	Red	Green	Red							
50M	Red	Green	Red							
52M	Red	Green	Red							
53M	Red	Green	Red							
54M	Red	Green	Red							
56F	Red	Green	Red							
57M	Red	Green	Red							
59M	Red	Green	Red	Yellow	Red					
60F	Red	Green	Red							
61M	Red	Green	Red							
62F	Red	Green	Red							
63F	Red	Green	Red							
64F	Red	Green	Red							
65M	Red	Green	Red							
66F	Red	Green	Red							
67F	Red	Green	Red							
68F	Red	Green	Red							
69M	Red	Green	Red							
71F	Red	Green	Red							
73F	Red	Green	Red							
74F	Red	Green	Red							
75M	Red	Green	Red							
76M	Red	Green	Red							
77F	Red	Green	Red							
78F	Red	Green	Red							
80M	Red	Green	Red							
81F	Red	Green	Red							
82F	Red	Green	Red							
83F	Red	Green	Red							
85M	Red	Green	Red							
86M	Red	Green	Red							
87F	Red	Green	Red							

Finally, two candidates came up for problem case 3 (candidates 11F and 48F), but only one presented 100% similarities (candidate 11F), and for the other one, more than half of the traits were not visible due to dental treatments (Figures 6 and 7). Of the three examples of problem cases shown, problem case 2 was the one in which an identification was reached the fastest (5 steps). In this case, if we reverse the order in which the traits are compared, from the most unequally distributed in the population to the most balanced, an identification would also be reached, however, with more steps, since it would be necessary to analyze the 10 traits (data not shown).

In summary, using a conservative approach (“explainable discrepancy” or “Insufficient evidence” results were considered without exclusion), the most likely candidate for positive identification was determined in eight steps for problem case 1, five steps for problem case 2, and two final candidates were identified in problem case 3, with only one achieving 100% similarity. In contrast, the less conservative approach (“explainable discrepancy” or “Insufficient evidence” results excluded the candidate) identified the most likely candidate in four steps for case 1, three steps for case 2, and four steps for case 3.

**Figure 6.** Dental traits profile of the problem case 3. Abbreviations of the traits are shown at the bottom lane. G: Grade, NV: Not visible, P: Present (Grade), Pa: Pattern, DT: Dental Treatment.

Hypocone	Lower 1 <sup>st</sup> Molar cusp number	Lower 2 <sup>nd</sup> Premolar cusp number	Upper canine distal accessory ridge	Lower 2 <sup>nd</sup> molar Groove pattern	Carabelli's cusp	Lower 2 <sup>nd</sup> molar cusp number	Upper lateral incisive interruption groove	Lower 1 <sup>st</sup> molar Groove pattern	Upper central incisive shoveling
G5	P(5)	G1	G0	Pa +	G4	A(4)	A	NV DT	G0
Hyp	L1MCN	M2MCN	UCDAR	L2MGP	CbII	L2MCN	ULIIG	L1MGP	UCIS

**Figure 7.** Matching-exclusion table integrating all candidate individuals for identification. The references of the candidates are listed in the first column.

	Hyp	L1MCN	L2PMCN	UCDAR	L2MGP	CbII	L2MCN	ULIIG	L1MGP	UCIS
1M										
2F										
3F										
4M										
5M										
6F										
7M										
8F										
9M										
11F										
12M										
14M										
15F										
16M										
17M										
18M										
19F										
20M										
21M										
22M										
23F										
24F										
25M										
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**DISCUSSION**

In this study, we show that using a comparative approach, dental traits (typically linked to anthropological research on population affinities) can also serve as a methodical forensic tool for human identification.

The frequencies of many traits vary among different populations; what is uncommon in one population may be very present in another. However, these differences tend to diminish due to increasingly widespread migration phenomena. In this study, we used the frequencies of these traits in a population from the north of Portugal for guidance purposes only.<sup>19</sup> The intention was to demonstrate the variability in the frequencies of dental trait profiles within the population. This variability in trait frequencies will, a priori, help decrease the number of candidates at each step of the matching-exclusion process. On one hand, more evenly distributed traits allow for discarding approximately half of the candidates (present or absent). In contrast, a more extreme unequal distribution favors, in theory, discarding many candidates at once when the trait is infrequent in the problem case. The chosen traits in this study are relatively common in different populations.<sup>16</sup> The very rare traits, despite their undeniable value for identification,<sup>20</sup> would not apply to this approach.

In the three problem cases used as examples of how the methodology works, the correct

identification of the problem individual was always achieved, despite very conservative rules being applied. When the trait cannot be observed in the problem case or the candidate (masked by dental treatment or missing tooth), the procedure continues. However, in a normal comparative identification process by the forensic odontologist, dental treatment or antemortem tooth loss in the candidate, not confirmed in the problem case, would be sufficient for unexplainable discrepancy and exclusion.

To simplify the procedure, only the left side of the jaw was used. The truth is that the method's effectiveness can be increased by using more information. Nevertheless, in real-life scenarios, the trend will be loss of information, with situations such as fragmented jaws or missing teeth. In such situations, we believe that this comparative exclusion method would still be useful. It is important to note that due to better oral health care among young people, fewer treatments are performed that alter dental morphology, which would help in identifying individuals through dental traits.

This comparative exclusion methodology could be ideally applied in various forensic scenarios involving mass casualties: accidents, natural disasters, terrorist acts, and historical or clandestine mass graves. For example, dental traits could be used to identify individuals from the same family in a mass grave.<sup>21</sup> This technique

preserves the remains without causing damage, and the images accurately show all the essential morphological details, keeping the original dimensions.<sup>7,22,23</sup> Yet, there may be challenges in capturing 3D images on the ground, at the site of the disaster. These challenges include limited access to the oral cavity in cases of burns or rigor mortis; the need to clean debris that could potentially affect the interpretation of morphological traits in 3D images; and finally, collecting images from fragile and partially fragmented jaws. Other limitations may arise at the time of analysis: training in observing and classifying dental traits is necessary; some training in dental medicine, particularly in dental anatomy, would be desirable to identify therapeutic modifications (the use of dental materials or dental devices is quite common, and can hide traits such as the groove pattern of the mandibular molars or accessory ridges on the canine, among others) (see images in Figures 2, 4, and 6); and when classifying certain dental traits, there is a level of subjectivity that should be considered.

What we present here is a first proposal for a methodology that has room to evolve: selection of other traits, selection of traits less subject to dental treatments, and application in other populations is recommended. Another possibility to enhance the discriminative power of this method could be to combine dental trait profiles with the presence and types of dental treatments carried out, and the presence-absence of teeth. Steps may also be taken in the direction of using artificial intelligence and deep learning. Automated comparative analysis, and comparison between different records (x-rays, tomography, and intraoral scans) is developing rapidly, and could help to grow this methodology.<sup>12,24-29</sup> In this context, several computer software programs already utilize dental coding systems to assist in the automated comparison of AM and PM data in mass disaster scenarios. DVI System International is the official software endorsed by INTERPOL and is among the most widely utilized tools for disaster victim identification.<sup>30</sup> Odontosearch, UDIM, and WinID are also software tools designed to assist forensic odontologists in human identification by utilizing dental records.<sup>31-33</sup> They primarily rely on radiographs and photographs to analyze dental characteristics, including missing teeth, restorations, and

anomalies. These software applications are continuously updated with more efficient versions and by integrating new tools. OdontoSearch 3.2 provides statistical values and an objective method for quantifying the relative frequency of dental patterns in the general population. It is based on individual patterns of missing, filled, and unrestored teeth on a large scale. Interestingly, it can statistically assess whether a specific dental pattern is rare or more prevalent within the studied population.<sup>31,34</sup> The study of dental trait patterns proposed in this work aligns perfectly with this approach. Integrating these traits into dental records would significantly enhance the database and improve the effectiveness of automated victim identification analysis.

However, the mentioned software applications do not rely on 3D images obtained through intraoral scanning. It is only recently that these images have started gaining wider use in dental clinics, and the potential for conducting intraoral scans on disaster victims is now being explored.<sup>6,35</sup> Promising software tools have been proposed for the comparative analysis of 3D-3D and 3D-2D images in the identification process.<sup>36</sup> Interestingly, other authors propose a Digital Dental Biometrics framework for human identification. Utilizing 3D dental point clouds with machine learning algorithms, they achieve a recognition rate of 100% using complete tooth crown contour samples.<sup>37</sup> This highlights the increasing adoption of new technologies for analyzing 3D images from intraoral scanners. The use of these images is now a reality, and their extensive application, particularly with the integration of Artificial Intelligence in the forensic field, is highly likely. Incorporating visible dental trait patterns present in 3D images could be a valuable advancement in the natural evolution of analytical methods for identification in forensic contexts.

## CONCLUSION

Using the matching-exclusion tables, the problem individuals appear to be reliably identified, despite the application of very conservative rules. Our research indicates that utilizing well-established dental morphological characteristics and modern 3D imaging technology could significantly enhance the efficient triage and identification of victims.

The key points of this study are:

1. The proposed exclusion comparative method based on dental morphological traits may be valuable for the triage and identification of victims.
2. Matching-exclusion tables integrate all candidate individuals for identification, and their dental trait profile can progressively be compared to a problem case.
3. AM and PM dental trait profiles are necessary for comparison.
4. 3D image quality allows dental traits comparison.
5. A simple collection of 3D images with an intraoral scanner of disaster casualty victims could speed up the identification process.

## REFERENCES

1. Cattaneo C, De Angelis D, and Grandi M. Mass Disasters, in Schmitt A, Cunha E, and Pinheiro J. Editors. *Forensic Anthropology and Medicine: Complementary Sciences From Recovery to Cause of Death*. Humana Press: Totowa, NJ; 2006. p 431-443.
2. Herschaft, E.E., *Manual of Forensic Odontology, Fourth Edition*. Taylor & Francis. 2011.
3. Prajapati G, Sarode SC, Sarode GS, Shelke P, Awan KH, Patil S. Role of forensic odontology in the identification of victims of major mass disasters across the world: A systematic review. *PLoS One* 2018;13(6):e0199791. doi:10.1371/journal.pone.0199791
4. Du H, Li M, Li G, Lyu T, Tian XM. Specific oral and maxillofacial identifiers in panoramic radiographs used for human identification. *J Forensic Sci* 2021;66(3):910-918. doi:10.1111/1556-4029.14673
5. de Boer HH, Blau S, Delabarde T, Hackman L. The role of forensic anthropology in disaster victim identification (DVI): recent developments and future prospects. *Forensic Sci Res* 2019;4(4):303-315. doi:10.1080/20961790.2018.1480460
6. Forrest A. Forensic odontology in DVI: current practice and recent advances. *Forensic Sci Res* 2019;4(4):316-330. doi:10.1080/20961790.2019.1678710
7. Santo E, Pinho T, Teixeira A, Perez-Mongiovi D. Use of intraoral three-dimensional images for the identification of dental morphological traits related to ancestry estimation. *J Forens Sci Med* 2021;7(2):70. doi:10.4103/jfsm.jfsm\_21\_21
8. Anh JW, Park JM, Chun YS, Kim M, Kim M. A comparison of the precision of three-dimensional images acquired by 2 digital intraoral scanners: effects of tooth irregularity and scanning direction. *Korean J Orthod* 2016;46(1):3-12. doi:10.4041/kjod.2016.46.1.3
9. Winkler J, Gkantidis N. Trueness and precision of intraoral scanners in the maxillary dental arch: an in vivo analysis. *Sci Rep* 2020;10(1):1172. doi:10.1038/s41598-020-58075-7
10. Al-Rammahi HM, Chai WL, Nabhan MS, Ahmed HMA. Root and canal anatomy of mandibular first molars using micro-computed tomography: a systematic review. *BMC Oral Health* 2023;23(1):339. doi:10.1186/s12903-023-03036-5
11. Wood RE. Forensic aspects of maxillofacial radiology. *Forensic Sci Int* 2006;159 Suppl 1:S47-55. doi:10.1016/j.forsciint.2006.02.015
12. Hassanaly M, Morais Caldas I, Teixeira A, Pérez-Mongiovi D. Application of CBCT technology in forensic odontology: A narrative review. *Current Forensic Science* 2023;1. doi:10.2174/2666484401666230516103852
13. Nuzzolese E. Missing people, migrants, identification and human rights. *J Forensic Odontostomatol* 2012;30 Suppl 1:47-59.
14. Austin D, King RE. The biological profile of unidentified human remains in a forensic context. *Acad Forensic Pathol* 2016;6(3):370-390. doi:10.23907/2016.039
15. Scott GR, Turner CG, Townsend GC, Martínón-Toirres M. *The Anthropology of Modern Human Teeth: Dental Morphology and its Variation in Recent and Fossil Homo sapiens*. 2<sup>nd</sup> ed. Cambridge Studies in Biological and Evolutionary Anthropology. Cambridge: Cambridge University Press; 2018.
16. Scott GR. and Irish JD. *Human Tooth Crown and Root Morphology: The Arizona State University Dental Anthropology System*. Cambridge: Cambridge University Press; 2017.
17. Scott GR, Pilloud M, Navega D, Coelho J, Cunha E, Irish J. RASUDAS: A new web-based application for estimating ancestry from tooth morphology. *Forensic Anthropology*. 2018;1(1):18-31. doi:10.5744/fa.2018.0003.
18. Venkatesh D, Sanchitha V, Smitha T, Sharma G, Gaonkar S, Hema KN. Frequency and variability of five non metric dental crown traits in the permanent maxillary dentitions of a racially mixed population from Bengaluru, Karnataka. *J Oral Maxillofac Pathol* 2019;23(3):458-465. doi:10.4103/jomfp.JOMFP\_144\_18
19. Marado LM, Silva AM. Dental and oral nonmetric traits in a Coimbra reference sample: testing intrasample chronological and spatial variation. *Archaeol Anthropol Sci* 2018;10(5):1165-1177. doi:10.1007/s12520-016-0455-4
20. Carneiro JL, Santos A, Magalhães T, Afonso A, Caldas IM. Human identification using dental techniques: A case report. *Med Sci Law* 2015;55(2):78-81. doi:10.1177/0025802414531752
21. Ríos L, García-Rubio A, Martínez B, Alonso A, Puente J. Identification process in mass graves from the Spanish Civil War II. *Forensic Sci Int* 2012;219(1-3):e4-9. doi:10.1016/j.forsciint.2011.11.021
22. Soto-Álvarez C, Fonseca GM, Viciano J, et al. Reliability, reproducibility and validity of the conventional buccolingual and mesiodistal measurements on 3D dental digital models obtained from intra-oral 3D scanner. *Arch Oral Biol* 2020;109(104575):104575. doi:10.1016/j.archoralbio.2019.104575
23. Travassos da Rosa Moreira Bastos R, Teixeira da Silva P, Normando D. Reliability of qualitative occlusal tooth wear evaluation using an intraoral scanner: A pilot study. *PLoS One* 2021;16(3):e0249119. doi:10.1371/journal.pone.0249119

24. Biggs M, Marsden P. Dental identification using 3D printed teeth following a mass fatality incident. *J Forensic Radiol Imaging*. 2019;18:1-3. doi:10.1016/j.jofri.2019.07.001
25. Putrino A, Valerio B, Marinelli E, Ciallella C, Barbato E, Galluccio G. Intraoral scanners in personal identification of corpses: Usefulness and reliability of 3D technologies in modern forensic dentistry. *Open Dent J* 2020;14(1):255-266. doi:10.2174/1874210602014010255
26. Damas, S., O. Cordon, and O. ibáñez, *Handbook on Craniofacial Superimposition: The MEPROCS Project*. 2020.
27. Mishra S, Yadav S, Yadav S, Verma P, Ojha S. Artificial intelligence: An advanced evolution in forensic and criminal investigation. *Current Forensic Science* 2022;1. doi:10.2174/2666484401666220819111603
28. Barrington S, Farid H. A comparative analysis of human and AI performance in forensic estimation of physical attributes. *Sci Rep* 2023;13(1):4784. doi:10.1038/s41598-023-31821-3
29. Mohammad N, Ahmad R, Kurniawan A, Mohd Yusof MYP. Applications of contemporary artificial intelligence technology in forensic odontology as primary forensic identifier: A scoping review. *Front Artif Intell*. 2022;5:1049584. doi:10.3389/frai.2022.1049584.
30. Interpol. Disaster Victim Identification. Accessed 13 of December 2024: <https://www.interpol.int/en/How-we-work/Forensics/Disaster-Victim-Identification-DVI>
31. Adams BJ. Establishing personal identification based on specific patterns of missing, filled, and unrestored teeth. *J Forensic Sci*. 2003;48(3):487-96.
32. Adserias-Garriga J, Rettger J, Hostetler SD. Principles in identification of human remains through forensic odontology. *Perspect Leg Forensic Sci*. 2024;1(1):10006. doi:10.70322/plfs.2024.10006
33. ABFO. WinID. Accessed 13 of December 2024: <https://abfo.org/winid/>
34. OdontoSearch 3.2. Accessed 14 of December 2024: <https://odontosearch.com>
35. Kofod Petersen A, Forgie A, Bindslev DA, et al. Automatic removal of soft tissue from 3D dental photo scans: an important step in automating future forensic odontology identification. *Sci Rep*. 2024;14:12421.
36. Ramírez G, Villegas AD, Kahana T, Cordon O, Ibáñez O. Artificial Intelligence-driven dental comparison for human identification in mass disaster. Presented at: 76th American Association of Forensic Sciences (AAFS) Annual Scientific Conference; 2024 Feb; Denver, USA.
37. Zhou Y, Yuan L, Li Y, Yu J. Digital Dental Biometrics for Human Identification Based on Automated 3D Point Cloud Feature Extraction and Registration. *Bioengineering* (Basel). 2024 Aug 28;11(9):873. doi:10.3390/bioengineering11090873.