Keywords:
forensic odontology; human identification; unidentified human remains; machine learning; Mexico forensic crisis; dental biometrics; disaster victim identification; postmortem analysis; artificial intelligence; clandestine graves.

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Unidentified Human Remains in Mexico (2006–2019): A Computational, Epidemiological, and Forensic Dental Analysis of the National Identification Crisis

Abstract
Background: Mexico faces an unprecedented humanitarian and forensic crisis. Between 2006 and 2019, at least 38,891 unidentified bodies accumulated in Servicios Médicos Forenses (SEMEFO) facilities across the country. Simultaneously, over 112,000 persons remain officially reported as missing, and an estimated 72,100 additional sets of unidentified human remains exist in state custody as of 2024. Forensic identification infrastructure has proven systemically insufficient: the United Nations Committee on Enforced Disappearances concluded that, under prevailing conditions, it would take 120 years to process existing remains without accounting for new cases.
Objective: This study presents a dual-component investigation integrating (I) advanced statistical analysis, machine learning, and data mining applied to a national public dataset of unidentified bodies, and (II) a critical scientific synthesis of forensic dentistry as an evidence-based, scalable, and technologically advanced solution for mass human identification in contexts of decomposition, carbonization, skeletonization, and clandestine burials.
Methods – Part I: The Quinto Elemento Lab – Crisis Forense dataset (N = 38,891 records; 11 variables; 2006–2019) was analysed using descriptive statistics, temporal trend modelling, Pearson and Spearman correlation coefficients, chi-square independence testing ($\chi^2 = 4{,}371.26$; $p < 0.0001$), K-means clustering ($k = 3$), and a composite forensic documentation index (FDI; range 0–4). Missing data patterns were systematically characterised.
Methods – Part II: A structured literature review was conducted across PubMed, Scopus, Web of Science, and IEEE Xplore (2020–2026) using terms including forensic odontology, dental biometrics, AI human identification, disaster victim identification, and postmortem dental analysis. Eighty-one peer-reviewed articles were critically evaluated.
Results – Part I: Unidentified bodies increased by 2,655.6% between 2006 and 2019 (CAGR = 29.1%; $r = 0.943$; $p < 0.0001$). The male-to-female ratio averaged 10.5:1. A total of 67.1% of bodies were disposed in common graves (fosa común). The Forensic Documentation Index (FDI) averaged 2.07/4.0, declining significantly over time (Spearman $r = -0.626$; $p = 0.017$). Cluster analysis identified three distinct state-level documentation profiles. Cause of death was categorised in only 45.4% of cases. A total of 17.7% of records lacked registration year.
Results – Part II: Current literature confirms that dental hard tissues (enamel, dentin, cementum) constitute the most biologically resistant structures in the human body, withstanding temperatures exceeding 1,000°C, prolonged burial, immersion, and advanced decomposition. Deep learning models applied to cone-beam computed tomography (CBCT) achieve identification accuracy of 85–99.1% depending on tooth type and algorithm. Dental prosthetics, implants, and restorations create individually unique, traceable forensic signatures. No national dental forensic database exists in Mexico.
Conclusions: This study demonstrates that Mexico's forensic crisis is statistically characterised by exponential growth, systemic documentation failure, and extreme institutional heterogeneity. Forensic dentistry — augmented by artificial intelligence and digital imaging — represents a scientifically robust, cost-effective, and scalable solution for the

mass identification of unidentified remains. Implementation of a National Forensic Dental Database, intraoral scanning protocols, and AI-assisted matching systems is urgently required.

1. Introduction

The identification of unidentified human remains (UHR) constitutes one of the most complex intersections of forensic science, public health, and international human rights law. In post-conflict and high-violence contexts, the capacity of forensic systems to identify the dead is directly linked to the state's obligation to investigate enforced disappearances, provide truth to families, and ensure reparations under international humanitarian law (International Convention for the Protection of All Persons from Enforced Disappearance, 2006; United Nations, 2022).

Mexico represents one of the most acute manifestations of this crisis globally. Since the militarised drug enforcement policy launched in 2006, the country has experienced an exponential escalation of violence resulting in mass casualty events, clandestine burials, and the systematic destruction of human remains — conditions that overwhelm conventional forensic identification methods. As of 2024, more than 112,000 individuals are officially reported as missing or disappeared, while national forensic services manage over 52,000 sets of unidentified human remains in formal custody (Comisión Nacional de Búsqueda, 2024; ICMP, 2024). More recent assessments suggest that the forensic backlog has continued to grow substantially. By 2025–2026, estimates produced by civil society organisations, academic initiatives, and international human rights bodies indicate that between 70,000 and 79,000 unidentified human remains may currently be under State custody awaiting identification, although no consolidated official national figure has yet been published (ARTICLE 19, 2026; Plataforma Ciudadana de Fosas–IBERO, 2026; CIDH, 2026). The United Nations Committee on Enforced Disappearances formally concluded that, under current institutional capacity, complete identification of existing UHR would require 120 years (UN CED, 2022).

The intersection of this crisis with forensic science practice reveals a critical structural problem: conventional identification methods become progressively less effective as case volume increases and remains undergo advanced taphonomic transformation. Visual recognition rapidly loses utility following decomposition, while fingerprint analysis depends on the preservation of soft tissues and is frequently precluded in skeletonised, carbonised, fragmented, or otherwise extensively decomposed remains. Although DNA analysis remains the gold standard for human identification, its large-scale application in the Mexican context faces substantial operational constraints, including high analytical costs, laboratory backlogs, limited processing capacity, the frequent absence of family reference samples, and the historical lack of a fully integrated national genetic comparison infrastructure. Furthermore, extreme forms of body destruction, such as incineration or the use of chemical agents, may significantly compromise DNA recovery. These limitations highlight the need for complementary identification modalities capable of operating effectively in complex forensic scenarios (Barbaro et al., 2025; Forensic Science International, 2024)..

Forensic odontology — the application of dental science to legal and medico-legal questions — emerges from this landscape as a uniquely resilient identification paradigm. The International Criminal Police Organization (INTERPOL) formally designates forensic odontology as one of three primary identifiers in its Disaster Victim Identification (DVI) protocol, alongside DNA analysis and fingerprinting, precisely because dental hard tissues maintain structural integrity under conditions that destroy every other biological marker (INTERPOL, 2023). Yet despite this recognition, no systematic national forensic dental database exists in Mexico, dental records are neither standardised nor digitised at a national level, and forensic odontological analysis is employed in a small minority of UHR cases (Quinto Elemento Lab, 2020; Identifying the Unidentified, ScienceDirect, 2026).

This paper presents a two-part scientific investigation. Part I applies advanced statistical modelling, machine learning, and data mining to a national public dataset documenting 38,891 unidentified bodies registered in Forensic Medical Service (SEMEFO) facilities across Mexico between 2006 and 2019, derived from the Quinto Elemento Lab – Crisis Forense database. Part II synthesises the current scientific evidence base for forensic dentistry as a primary identification technology, with particular emphasis on artificial intelligence applications, dental biometrics, postmortem imaging, and the specific utility of dental analysis in extreme taphonomic conditions. Together, the two parts construct an integrated scientific argument for the urgent implementation of AI-augmented forensic dental identification systems in Mexico.

The study is positioned as one of the first Latin American works to integrate computational epidemiology, data science, and forensic odontology to address the identification crisis, and its findings carry direct implications for national forensic policy, international human rights compliance, and the design of next-generation forensic identification infrastructure.

2. Literature Review

2.1 The Global Burden of Unidentified Human Remains

The global challenge of unidentified human remains is extensive. The burden of UHR disproportionately affects lower-income countries with high rates of homicide, armed conflict, natural disasters, or mass migration (ICMP, 2024). In the United States, the National Missing and Unidentified Persons System (NamUs) manages more than 24,000 active missing persons cases and 14,600 unidentified decedent cases (NamUs, 2024). In Latin America, Brazil, Colombia, Guatemala, and Mexico have been documented as centres of forensic crisis, particularly in relation to victims of organised violence (WOLA, 2025; Springer, 2025).

A scoping review published in the journal Forensic Science International (2026) specifically examined the identification crisis in Mexico, concluding that between 2000 and 2024 approximately 101,638 individuals were reported missing, contributing to the saturation of forensic services and creating a systemic failure in the identification pipeline. The study mapped international advances in antemortem/postmortem (AM/PM) data integration and found a significant implementation gap between available scientific technology and forensic practice in Mexico (ScienceDirect, 2026).

2.2 Forensic Odontology: Historical Development and Scientific Foundations

The practice of forensic odontology is documented as early as 49 CE, when Agrippina identified Lollia Paulina by her teeth following decapitation (Chaurasia et al., Egyptian J Forensic Sci, 2026). The modern era of forensic dentistry is typically dated to 1897, when Dr. Oscar Amoedo systematically employed dental comparisons to identify 126 victims of the Bazar de la Charité fire in Paris, establishing the foundational protocol of antemortem-postmortem dental record comparison (Amoedo, 1897; Chaurasia et al., 2026).

Contemporary forensic dentistry encompasses human identification through dental record comparison, biological profiling (age, sex, ancestry, and stature estimation), bite mark analysis, dental trauma documentation, and population-level dental archaeology. The unique combination of biological uniqueness, structural durability, and the lifelong accumulation of individuating characteristics through dental treatment makes the dentition one of the most powerful identification substrates known to forensic science (Emam, Cureus, 2024; Radu et al., Diagnostics, 2025).

2.3 Biological Durability of Dental Hard Tissues

The exceptional forensic utility of teeth derives fundamentally from their unique structural biology. Enamel — the outer layer of the dental crown — is the hardest substance produced by the mammalian body, composed of approximately 96% hydroxyapatite ($Ca_{10}(PO_4)_6(OH)_2$) organised into densely packed crystalline prisms arranged in Hunter-Schreger bands (Barbaro et al., 2025). This organisation confers resistance to thermal, chemical, mechanical, and microbial degradation far exceeding any other biological tissue.

A systematic review by Barbaro et al. (Egyptian Journal of Forensic Sciences, 2025) synthesised current evidence on the effects of extreme heat on dental structures, finding that enamel provides critical thermal insulation to the subjacent dentin and pulp chamber. Nuclear DNA degrades significantly above 200°C, while mitochondrial DNA (mtDNA) in dentin tubules and cementum remains amplifiable at temperatures exceeding 400°C. The review concluded that teeth are 'highly reliable sources of DNA in forensic contexts involving heat exposure' and identified the urgent need for standardised protocols for thermal exposure, DNA extraction, and reporting.

Dentin, composed of approximately 70% hydroxyapatite and 30% organic matrix, retains odontoblastic processes within a network of dentinal tubules that act as protected channels for mtDNA preservation. The cementum, covering the root surface, entraps cementocytes with preserved DNA through blood residues, accessory canals, and periodontal fibres (Forensic Science International, 2024). Together, these three tissue layers form a composite biological container of exceptional forensic durability.

2.4 Artificial Intelligence and Digital Technologies in Forensic Dentistry

The integration of artificial intelligence into forensic odontology represents one of the most significant scientific advances of the current decade. A systematic review by Hamidi et al. (Neural Computing and Applications, Springer, 2025) — following PRISMA 2020 guidelines and covering the period 2020–2024 in Web of Science — found that AI applications in forensic dental image analysis have experienced dramatic growth, focusing on age estimation, sex classification, and human identification through panoramic and CBCT radiography.

Convolutional neural networks (CNNs) applied to dental panoramic radiographs (orthopantomograms, OPG) have demonstrated outstanding performance metrics: 99.1% precision in natural teeth detection, 80.6% in prosthesis detection, 81.2% in treated root canals, and 96.8% in dental implants (Mohammad et al., Frontiers in AI, 2022). Automated antemortem-postmortem radiographic comparison algorithms have reported average accuracy of 85% (Heinrich et al., 2022). The narrative review by Radu et al. (Diagnostics, PMC, October 2025) synthesised 81 peer-reviewed articles published between 2015 and 2025, confirming that CBCT, 3D scanning, and intraoral imaging demonstrate 'improved diagnostic consistency compared with conventional techniques' across all forensic odontology subtasks.

The most recent publication identified in this review — Chaurasia et al. (Egyptian Journal of Forensic Sciences, Volume 16, March 2026) — concluded that 'the integration of AI into forensic odontology has significantly advanced the field by enhancing analytical precision, accelerating data processing, and improving reliability in human identification,' establishing 'new standards in forensic practice with the potential to significantly impact legal investigations and human identification processes in both routine cases and mass disaster events.'

2.5 Dental Identification in Extreme Taphonomic Contexts

The forensic literature consistently demonstrates that dental identification retains validity under conditions that render all other primary identifiers inaccessible. A landmark 2024 study in Forensic Science International (Volume 361, Article 112143) investigated DNA extraction from decomposed remains across all tooth morphotypes in three deceased individuals (N = 52 teeth). Contrary to international guidelines recommending molars, the study found that premolars, followed by canines, achieved the highest DNA profiling success rates, challenging established forensic protocols and identifying a critical knowledge gap requiring protocol revision.

The dental autopsy concept — comprehensive postmortem dental examination generating biological profile and individuating characteristics even in edentulous individuals — was exemplified in the case study by Nuzzolese & Torreggianti (Forensic Sciences Research, 2021), where a decomposed, edentulous body was definitively identified through 42 periapical radiographs documenting prosthetic work and mandibular osteosynthesis, without requiring DNA analysis. This case demonstrates the identification power of prosthodontic and restorative dental evidence.

In mass grave and mass disaster contexts, forensic dental evidence has been operationalised at scale. Brkic et al. documented odontological identification of 1,000 human remains from mass graves in Croatia, establishing a methodological template for high-volume dental identification that is directly applicable to the Mexican context (International Journal of Legal Medicine, 2000; cited by WHO DVI guidance, 2024). The Carbodent Scale, introduced by Nuzzolese, Aliberti & Di Vella (MDPI, 2024), provides a standardised colorimetric system for classifying heat damage to dental remains, enabling systematic recovery of evidence from carbonised bodies — a critical tool in cases where bodies have been incinerated to obstruct forensic investigation.

2.6 Dental Prosthetics and Implants as Forensic Identifiers

The expanding prevalence of dental prosthetics and implants worldwide has created new forensic identification pathways. A case report published in Forensic Science International (2026) documented the first confirmed identification of a cremated, unidentified individual using industrial computed tomography to recover the batch lot number of a Straumann® dental implant — a finding that traced the patient to a specific dental clinic and enabled positive identification without DNA analysis or dental record comparison. The study reviewed literature on implant recognition software, CBCT-based implant identification, and AI-assisted implant system classification.

Khandelwal et al. (Cureus, May 2025; PMC12143587) systematically reviewed dental implant identification methods in forensic practice, noting that titanium implants survive cremation temperatures, resist corrosion and degradation, and frequently retain manufacturer-encoded identification data accessible through CT scanning. The review identified a critical gap: despite the scientific readiness of implant-based identification, forensic awareness, standardised databases of implant systems, and AI identification tools remain insufficiently developed for routine practice.

2.7 The Mexican Forensic Context: Institutional Crisis and Scientific Opportunity

Mexico's forensic identification infrastructure has been characterised by multiple independent analyses as critically overwhelmed, institutionally fragmented, and technologically underdeveloped. The Quinto Elemento Lab – Crisis Forense investigation (2020), the most comprehensive public documentation of the crisis, revealed that 38,891 unidentified bodies accumulated in SEMEFO facilities between 2006 and 2019, with 67.1% ultimately transferred to State-managed common graves. Alarmingly, among these cases, 58.6% lacked genetic profiles and 53.3% had no basic identification documentation (archivo básico), indicating that a substantial proportion were buried without the minimum forensic information required for future identification efforts. .

Key structural deficiencies documented in the literature include: (1) absence of a national forensic dental database; (2) lack of standardised postmortem dental examination protocols; (3) non-digitised antemortem dental records in the majority of Mexican dental practices; (4) absence of forensic odontologists in most SEMEFO facilities; (5) heterogeneous state-level forensic capacity; and (6) no interoperability between state-level forensic information systems (WOLA, 2025; CIVICUS, 2025; ICMP, 2024).

The Extraordinary Mechanism for Forensic Identification (MEIF), established in 2019, and the National Forensic Data Bank (BNDF), formally launched in 2023, represent important institutional efforts to address Mexico's forensic identification crisis (UNFPA, 2022; Fiscalía General de la República, 2023; ONU-DH México, 2023). However, both initiatives have faced significant operational, coordination, funding, and interoperability challenges, limiting their capacity to fully address the growing backlog of unidentified human remains (Centro Prodh, 2023; Animal Político, 2024; Fundar, 2026; Quinto Elemento Lab, 2026). Furthermore, recent reports indicate that the MEIF ceased operating as originally conceived in 2024, while concerns regarding the effective implementation and nationwide integration of the BNDF persist (A Dónde Van los Desaparecidos, 2024; IMER Noticias, 2024; Nexos, 2026). Moreover, neither framework has incorporated a dedicated national forensic dental database, standardised digital dental record protocols, or AI-assisted dental comparison systems as core components of the identification process. Given the demonstrated durability, individualising potential, and digital compatibility of dental evidence, this omission represents a missed scientific and humanitarian opportunity within Mexico's broader forensic identification strategy..

3. Materials and Methods

3.1 Data Source and Ethical Considerations

This study uses the public dataset 'Cuerpos no identificados México 2006–2019 — Versión año y sexo de registro,' published by Quinto Elemento Lab as part of the investigative journalism project #CrisisForense. The dataset was obtained through formal access requests under Mexico's transparency legislation (Ley General de Transparencia y Acceso a la Información Pública) directed to SEMEFO facilities across 32 states. The data is fully public, aggregated (individual record level without personal identifiers), and curated for research and public interest use. No

ethical committee approval was required for this secondary analysis of a public administrative dataset.
The literature review component of this study adheres to PRISMA 2020 guidelines for systematic search reporting. No primary human subjects data was collected or processed.

3.2 Dataset Characteristics

The dataset comprises 38,891 individual records (one row = one unidentified body) with 11 variables: registration year (año), state (estado), sex (sexo), cause of death (causa de muerte), location of discovery (lugar de hallazgo), original storage location (lugar de resguardo original), final storage location (lugar de resguardo), death certificate status (certificado de defunción), genetic profile status (perfil genético), autopsy status (necropsia), and basic documentation file status (archivo básico). Records span 32 Mexican states and the 2006–2019 period, with an additional 6,869 records (17.7%) lacking registration year.

3.3 Part I: Statistical and Computational Methods

3.3.1 Data Preprocessing

Raw data were loaded using Python 3.11 with the pandas (v2.0), numpy (v1.24), and scikit-learn (v1.3) libraries. The year variable was converted to numeric using pd.to_numeric() with coercion of non-numeric values to NaN. Categorical variables were cleaned for standardisation of labels. A total of 158 records with missing cause of death or location fields were retained for all analyses except those specific to those variables.
Four binary forensic documentation indicators were constructed by mapping 'sí' (yes) → 1 and 'no' → 0, with all other values (including 'sin dato', 'sin sistematizar', 'en proceso') treated as missing (NaN) for binary analyses but excluded from binary counts for the composite index. A Forensic Documentation Index (FDI) was computed as the row-wise sum of the four binary indicators (range 0–4), where higher values indicate more complete forensic documentation.

3.3.2 Descriptive Statistics

Descriptive analysis included frequency distributions for all categorical variables, annual counts and percentage change calculations, male-to-female ratios by year, and percentage distributions of final disposition categories. Missing data were characterised at the variable level and by state.

3.3.3 Inferential Statistics

Pearson correlation (r) was used to quantify the linear relationship between registration year and annual case count (N = 14 annual data points). Spearman rank correlation (ρ) was applied to assess the monotonic relationship between year and mean FDI, given the non-normality of the documentation score distribution. Chi-square (χ^2) independence tests assessed associations between categorical variables (sex × final disposition). All tests used $\alpha = 0.05$. Statistical computations were performed using scipy.stats (v1.11).

3.3.4 K-Means Clustering

To identify state-level documentation profiles, K-means clustering was applied to the state-aggregated dataset (N = 32 states). Feature vector comprised: percentage positive for each of the four documentation indicators, mean FDI, percentage male, and percentage sex-unknown. Features were standardised using StandardScaler (zero mean, unit variance) prior to clustering. The optimal number of clusters (k = 3) was determined by visual inspection of the within-cluster sum of squares (elbow method) and cluster interpretability. Algorithm was run with n_init = 10 and random_state = 42 for reproducibility. Implementation used scikit-learn KMeans.

3.3.5 Cause of Death Classification

The 3,683 unique cause of death categories were reclassified into six macro-categories using a keyword-based algorithm: violent (homicidio, violenta, disparo, arma de fuego, decapitación, descuartizamiento, estrangulamiento, traumatismo); natural (natural, infarto, cirrosis, enfermedad, bronconeumonía); accidental (tránsito, atropello, accidente, sumersión); suicide (suicidio, ahorcamiento); unknown (sin dato, sin sistematizar, s/d); and other. This classification was performed using Python string matching on lowercased cause fields.

3.3.6 Temporal Trend Analysis

Annual documentation indicators were tracked longitudinally for all four binary variables (necropsy, death certificate, genetic profile, basic file). The compound annual growth rate (CAGR) of total case volume was computed as CAGR = ((V_2019/V_2006)^(1/13) − 1) × 100. Percentage of bodies sent to common graves was computed by year to examine temporal changes in final disposition.

3.4 Part II: Literature Review Methods

A structured literature search was conducted across PubMed/MEDLINE, Scopus, Web of Science, Google Scholar, and IEEE Xplore using Boolean search strings combining core terms: 'forensic odontology' OR 'forensic dentistry' AND 'artificial intelligence' OR 'machine learning' OR 'deep learning'; 'dental identification' AND 'decomposition' OR 'skeletonized' OR 'burned'; 'disaster victim identification' AND 'dental'; 'unidentified human remains' AND 'Mexico'; 'CBCT forensic' AND 'identification'.
Inclusion criteria: peer-reviewed articles in English or Spanish; published 2020–2026; reporting original research, systematic reviews, narrative reviews, or case studies on forensic odontology, AI-assisted dental identification, DNA from dental tissues, or the Mexican identification crisis. Exclusion criteria: conference abstracts without peer review, publications prior to 2020 (unless seminal references), grey literature without scientific validation. From 312 initial records retrieved, 81 articles meeting full eligibility criteria were included. An additional 18 pre-2020 seminal references were included for methodological and historical context.

4. Results

4.1 Part I: Statistical and Data Mining Analysis of the Crisis Forense Database

4.1.1 Overall Dataset Characteristics and Volume Dynamics

The Quinto Elemento Lab dataset documents 38,891 unidentified bodies registered in Mexican SEMEFO facilities across 32 states and the Federal entity between 2006 and 2019. This figure represents a conservative lower bound: it excludes bodies not reaching SEMEFO, fragmented remains counted as individual cases, and clandestine grave exhumations not formally processed through SEMEFO.

Annual case volume grew from 178 cases in 2006 to 4,905 in 2019, representing an absolute increase of 2,655.6% over 13 years (CAGR = 29.1%). The Pearson correlation between registration year and annual case count was r = 0.943 ($p < 0.0001$), confirming a near-perfect linear growth trend. Inflection points were observed at 2009 (jump from 620 to 1,443 cases; +133%), coinciding with escalation of the Calderón drug policy military operations, and at 2016 (2,902 cases; +24.2%), coinciding with the expansion of criminal territorial disputes following cartel fragmentation.

Table 1. Annual distribution of unidentified bodies in Mexican SEMEFO facilities (2006–2019), sex composition, and forensic documentation index (FDI) by year.

Year	Total N	Males	Females	Sex unknown	Male/female ratio	% Common grave	FDI mean	% Necropsy
2006	178	128	31	19	4.13	85.4	1.76	100.0
2007	433	371	25	37	14.84	85.2	2.05	100.0
2008	620	469	50	101	9.38	83.2	2.20	100.0
2009	1,443	1,256	123	64	10.21	68.5	1.84	100.0
2010	2,194	1,850	181	163	10.22	72.1	2.00	100.0
2011	2,434	1,961	140	333	14.01	65.9	1.94	99.8
2012	2,225	1,904	185	136	10.29	72.1	1.95	99.9
2013	2,374	1,892	201	281	9.41	68.7	1.80	100.0
2014	2,282	1,914	204	164	9.38	68.8	1.77	99.6
2015	2,336	1,959	199	178	9.84	70.9	1.80	99.6
2016	2,902	2,435	202	265	12.05	71.7	1.79	98.9
2017	3,288	2,531	228	529	11.10	63.9	1.74	98.3
2018	4,408	3,450	286	672	12.06	57.0	1.78	99.1
2019	4,905	3,614	320	971	11.29	38.2	1.58	98.2

Note: FDI = Forensic Documentation Index (0–4 composite score). Male/female ratios computed excluding sex-unknown records. % common grave = percentage of annual cases with final destination recorded as fosa común. FDI decline over time: Spearman $\rho = -0.626$, $p = 0.017$.

4.1.2 Sex Distribution and Gender Disparity Analysis

Of 38,891 total records, 25,833 (66.4%) were registered as male, 2,419 (6.2%) as female, and 10,639 (27.4%) had no sex recorded (sin dato). The male-to-female ratio across the full dataset was 10.7:1, ranging from a minimum of 4.1:1 in 2006 to a maximum of 14.8:1 in 2007 (see Table 1). This ratio substantially exceeds expected sex ratios in natural mortality and accidental death contexts, strongly suggesting a population composed predominantly of victims of targeted or organised violence.

Chi-square testing confirmed highly significant associations between sex and final disposition ($\chi^2 = 4{,}371.26$; df = 16; $p < 0.0001$), indicating differential treatment of male versus female unidentified remains within the forensic processing system. The proportion of records with sex unrecorded increased from 10.7% in 2006 to 19.8% in 2019, representing a worsening data quality trend at the precise period of greatest case volume — suggesting institutional collapse rather than improved anonymisation.

4.1.3 Geographic Distribution and State-Level Patterns

The ten highest-volume states account for 73.4% of all records: Estado de México (5,490; 14.1%), Ciudad de México (5,135; 13.2%), Baja California (4,599; 11.8%), Jalisco (3,682; 9.5%), Chihuahua (2,975; 7.6%), Nuevo León (1,550; 4.0%), Sonora (1,442; 3.7%), Tamaulipas (1,176; 3.0%), Veracruz (1,144; 2.9%), and Puebla (1,135; 2.9%). This geographic concentration is consistent with the spatial distribution of organised crime territorial control and military operation intensity documented in independent security analyses.

Table 2. K-means cluster analysis results: state-level forensic documentation profiles (k = 3).

Cluster	States (representative)	FDI mean	% Necropsy	% Genetic profile	N bodies
A: High documentation	Chihuahua, Nuevo León, B.C.Sur, Oaxaca, Zacatecas, Chiapas	3.40	100.0	100.0	6,214
B: Intermediate documentation	Estado de México, Federal	2.54	100.0	100.0	623
C: Partial documentation	Jalisco, Tamaulipas	1.59	96.5	76.0	4,501
D: No comparable data	All remaining states	—	—	—	27,553

Note: Cluster analysis applied to states with sufficient data for all four FDI indicators. States with zero values across all documentation fields (e.g., Veracruz, Puebla, Guerrero) were excluded from clustering as they represent total documentation failure rather than a documentation profile. FDI = Forensic Documentation Index; B.C.Sur = Baja California Sur.

4.1.4 Forensic Documentation Index Analysis

The Forensic Documentation Index (FDI), computed as the sum of four binary forensic documentation indicators, yielded a dataset-level mean of 2.07 (SD = 1.41; range 0–4). The distribution was bimodal, with pronounced peaks at FDI = 1 (n = 12,143; 31.2%) and FDI = 4 (n = 10,969; 28.2%), indicating a polarised system where approximately one-third of cases have nearly complete documentation and one-third are severely under-documented. A total of 4,757 records (12.2%) had FDI = 0, meaning no positive forensic documentation indicator was recorded.

The Spearman correlation between registration year and annual mean FDI was ρ = −0.626 (p = 0.017), demonstrating a statistically significant deterioration in forensic documentation quality as case volume increased. This inverse relationship is consistent with institutional capacity saturation: as SEMEFO facilities processed exponentially more cases, per-case documentation quality declined. This finding has critical policy implications, as it suggests that documentation failure is not random but systematically worsens under high-load conditions.

Table 3. Forensic Documentation Index (FDI) distribution and individual indicator rates across the full dataset (N = 38,891).

Forensic indicator	N positive (sí)	% positive	N negative (no)	N missing/unknown	Coverage completeness
Necropsy (autopsy)	32,985	84.8%	193	5,713	85–100%
Death certificate	18,295	47.0%	1,825	18,771	47.0%
Genetic profile	14,785	38.0%	795	23,311	38–40%
Basic documentation file	14,555	37.4%	3,126	21,210	37–39%
FDI composite (mean)	2.07 / 4.0	51.8%	—	—	Bimodal distribution

Note: 'Missing/unknown' includes 'sin dato', 'sin sistematizar', 'en proceso', and null values. Coverage completeness reflects the proportion of records with a definitive positive or negative recording, excluding ambiguous states. Genetic profile column contains a typographic inconsistency ('pefil genético') in the original dataset, preserved as documented in the data source.

4.1.5 Final Disposition Analysis

Analysis of the lugar de resguardo (final disposition) variable revealed that 26,105 bodies (67.1%) were sent to common graves (fosa común), 3,801 (9.8%) remained in SEMEFO facilities, and 2,190 (5.6%) were donated to universities for academic use. A combined 2,144 records (5.5%) had final disposition recorded as unknown to the authority or unspecified. The percentage of bodies sent to common graves declined from 85.4% in 2006 to 38.2% in 2019, though this trend reflects redistribution to other disposal categories rather than identification success.

4.1.6 Cause of Death Classification

The original dataset contained 3,683 unique cause of death entries, demonstrating extreme taxonomic heterogeneity incompatible with epidemiological analysis. Application of the keyword classification algorithm produced the following macro-category distribution: unknown/unregistered (54.6%; n = 21,250), natural (15.7%; n = 6,102), violent (12.7%; n = 4,929), other/unclassifiable (10.7%; n = 4,168), accidental (5.5%; n = 2,119), and suicide (0.8%; n = 323). The violent cause category is certainly underestimated, as the 'other' and 'unknown' categories likely contain misclassified or insufficiently described violent deaths.

State-level violent death percentages varied dramatically: Chihuahua (36.8%), Tamaulipas (32.5%), Nuevo León (29.5%), Ciudad de México (12.0%), Jalisco (6.1%), and Puebla (22.2%). States with zero percent violent cause recorded (e.g., Estado de México, Baja California, Veracruz) reflect documentation failure rather than actual cause distribution, as these states are among the highest-violence jurisdictions in independent criminological analyses.

4.1.7 Anomaly Detection and Data Quality Assessment

A total of 6,869 records (17.7%) lacked a registration year, constituting a major data quality anomaly that prevents temporal analysis for nearly one-fifth of the dataset. This is not a uniform distribution across states: concentrated in specific jurisdictions, the pattern suggests discrete episodes of retroactive data entry, batch transfers from external facilities, or systematic record-keeping failures rather than random missingness.

The variable 'lugar de resguardo original' contains 171 unique entries, many referring to external databases not integrated into the public release ('Ver base LG'), preventing complete final disposition analysis for 3,595 records (9.2%). The cause of death variable contains 3,683 unique free-text entries without standardised coding — evidence of the complete absence of ICD-10 or equivalent coding in the forensic cause-of-death recording system. Together, these anomalies constitute a methodological critique of the data source with significant implications for interpretation: all quantitative findings from this dataset should be interpreted as minimum estimates subject to unknown systematic biases.

4.2 Part II: Forensic Dentistry in Advanced Decomposition — Scientific Evidence Synthesis

4.2.1 The Unique Biological Architecture of Dental Hard Tissues

The forensic superiority of teeth derives from a coincidence of structural, chemical, and anatomical properties with no parallel in the biological sciences. Hydroxyapatite ($Ca10(PO4)6(OH)2$), the principal mineral component of enamel (96% by weight), forms an interlocking crystalline lattice that confers Vickers hardness values of 340–431 HV — far exceeding cortical bone (30–40 HV) and approaching synthetic ceramic composites used in engineering applications (Barbaro et al., 2025; Nanci, 2024). The resulting tissue is insoluble in most biological fluids, resistant to enzymatic degradation, and capable of maintaining structural integrity over geological timescales under appropriate conditions.

Critically for forensic applications, this architecture creates a protective 'biological vault' for the dental pulp — a highly vascular, cell-rich connective tissue contained within the pulp chamber and root canals. Under forensic conditions of decomposition, the pulp degrades rapidly due to autolysis and microbial colonisation; however, the dentin-enamel complex continues to protect mtDNA in dentin tubules and cementum long after pulp tissue is no longerviable.Although recoverable DNA may also be obtained from skeletal tissues in advanced decomposition or fully skeletonised remains, teeth provide an additional layer of biological protection against both natural taphonomic processes and certain anthropogenic destructive events. Consequently, dental tissues may preserve identifiable genetic material under conditions in which DNA recovery from other tissues becomes increasingly challenging, including cases involving extensive decomposition or moderate thermal exposure.

4.2.2 Performance Under Extreme Taphonomic Conditions

Table 4 summarises the performance of dental identification across the principal taphonomic scenarios encountered in the Mexican forensic context, based on systematic review of the current literature.

Table 4. Performance of forensic dental identification across extreme taphonomic conditions relevant to the Mexican context.

Taphonomic condition	Dental tissue integrity	Forensic identification method	Evidence quality	Key reference
Advanced decomposition (>30 days)	Enamel and dentin intact; pulp degraded	Morphological comparison; mtDNA from dentin/cementum	High	FSI Vol.361 (2024)
Skeletonisation	Crown and root structure preserved	Record comparison; dental radiomics; mtDNA	High	Radu et al. (2025)
Carbonisation <400°C	Enamel cracked; dentin and cementum intact	mtDNA extraction; Carbodent Scale	Moderate–High	Barbaro et al. (2025)
Carbonisation 400–900°C	Enamel fragmented;	mtDNA from	Moderate	Nuzzolese

Taphonomic condition	Dental tissue integrity	Forensic identification method	Evidence quality	Key reference
	root structure recoverable	cementum; AI image reconstruction		et al. (2024)
Cremation >900°C	Enamel destroyed; implants/restorations survive	Implant lot number CT; prosthetic record	Low–Moderate	FSI 2026 (implant CT)
Prolonged aquatic submersion	Enamel intact; demineralisation of dentin possible	Morphological comparison; prosthetics	Moderate–High	Emam, Cureus (2024)
Fragmentation/dismemberment	Individual teeth recoverable as complete units	Record comparison of individual teeth	High	Radu et al. (2025)
Acid exposure	Variable by acid type and concentration	Micro-CT reconstruction; AI pattern analysis	Low–Moderate	Thurzo et al. (2022)

Note: Evidence quality ratings based on reported sensitivity/specificity or identification accuracy in peer-reviewed literature. mtDNA = mitochondrial DNA. CT = computed tomography. AI = artificial intelligence. FSI = Forensic Science International.

4.2.3 Dental Uniqueness and Biometric Individuation

The forensic concept of dental individuation rests on the principle that no two oral cavities produce identical dental patterns across an individual's lifetime. The combination of tooth morphology (crown and root shape, cusp pattern, accessory ridges, pulp chamber dimensions), dental pathology (caries, abrasion, attrition, erosion, periapical pathology), restorative history (filling materials, restoration morphology, prosthetic devices, implant systems), developmental anomalies (dens invaginatus, taurodontism, gemination, fusion, dilaceration), and iatrogenic modifications (endodontic treatment, orthodontic appliances, extraction sites) generates a multi-dimensional biometric space of extraordinary complexity.

Quantitative estimates suggest that the number of possible dental status combinations for a full dentition exceeds 10^250, making the probability of two individuals sharing an identical complete dental profile for practical purposes equivalent to zero (Chen & Jain, IEEE Trans. Pattern Analysis, 2005; cited by Mohammad et al., 2022). This biological uniqueness is preserved in both hard copy (traditional radiographs, dental charts) and digital (CBCT, intraoral scan, panoramic radiograph) antemortem record formats, creating a stable biometric record capable of matching to postmortem dental findings across any temporal interval.

4.2.4 Artificial Intelligence in Forensic Dental Identification: Current State and Performance

The application of machine learning and deep learning to forensic odontology tasks has transformed the technical landscape of the discipline. Figure 1 (conceptual framework, described textually below) maps the principal AI application domains in forensic dentistry, their algorithmic approaches, and reported performance metrics.

In dental record comparison — the core forensic identification task — CNNs applied to panoramic radiographs have demonstrated automated detection of natural teeth at 99.1% precision, treated root canals at 81.2%, prostheses at 80.6%, and implants at 96.8% (Mohammad et al., 2022). Automated antemortem-postmortem OPG comparison algorithms have reported matching accuracy of 85% (Heinrich et al., 2022), a figure expected to improve substantially with larger training datasets. Three-dimensional dental superimposition studies using intraoral scan data have demonstrated proof-of-concept for digital matching in personal identification (Yu et al., J Forensic Sci, 2024). For biological profiling tasks, sex estimation from CBCT images of molar pulp chambers using machine learning classifiers achieved 93.7% training accuracy (KNN) and 89.1% testing accuracy (neural network; Esmaeilyfard et al., 2021, cited in Mohammad et al., 2022). Dental age estimation using deep learning models applied to panoramic radiographs has been validated across multiple populations and demonstrates performance comparable to expert odontologists in controlled studies (Matthijs et al., as cited in Sinha et al., 2025). Geometric morphometric analysis combined with artificial neural networks has enabled sex estimation from 3D dental crown morphology with high accuracy in Italian populations (Oliva et al., Healthcare, 2021), establishing a methodological template for population-specific applications.

Table 5. Summary of AI application domains in forensic odontology: algorithms, tasks, and reported performance metrics (2020–2026).

Application domain	Algorithm / approach	Reported accuracy / metric	Dataset	Reference
Natural teeth detection	CNN (EfficientDet-D3)	99.1% precision	OPG radiographs	Mohammad et al. (2022)
Dental implant detection	CNN (OPG-based)	96.8% precision	OPG radiographs	Mohammad et al. (2022)
AM/PM radiograph matching	Computer vision	85.0% accuracy	Paired OPG	Heinrich et al. (2022)
Sex classification (CBCT)	KNN / neural network	89.1–93.7% accuracy	CBCT images	Esmaeilyfard et al. (2021)
CBCT feature detection (meta-analysis)	Deep learning (pooled)	~93% accuracy; ~91–93% recall	Multi-dataset	PMC12731901 (2025)
Dental age estimation	Deep learning / DNN	Comparable to expert	Panoramic radiographs	Matthijs et al. (2025)
3D sex estimation	ANN + geometric morphometrics	High (pilot study)	3D dental scans	Oliva et al. (2021)
Implant lot ID (CT)	Industrial CT	Single case confirmed	Cremated remains	FSI (2026)

Note: AM/PM = antemortem/postmortem. CNN = convolutional neural network. KNN = k-nearest neighbours. DNN = deep neural network. ANN = artificial neural network. OPG = orthopantomogram (panoramic radiograph). CBCT = cone-beam computed tomography.

4.2.5 DNA Recovery from Dental Tissues in Advanced Decomposition

The dual utility of teeth as both morphological and genetic identification substrates is a defining advantage over all competing identification methods. When conventional DNA sources (blood, soft tissue, bone) are unavailable due to advanced decomposition, the dental complex frequently retains amplifiable genetic material. A study in Forensic Science International (Volume 361, 2024) systematically investigated DNA yield from all 32 human tooth morphotypes across 52 teeth from three deceased individuals, comparing two extraction methods. The study found that premolars yielded the highest profiling success rates, followed by canines — contradicting international guidelines recommending molars and necessitating a revision of standard forensic DNA sampling protocols.

A landmark case study from the Autonomous University of Nuevo León, Mexico (Chávez-Briones et al., Medicina, 2023) documented the world's first identification of skeletal remains using DNA from deciduous teeth preserved by a family member for over 30 years. DNA typing of dental pulp from three deciduous molars produced STR profiles that matched the fragmented, skeletonised, and partially burned remains, with a random match probability of 1 in 2.70 × 10^{21}. This case has direct relevance for the Mexican context, where families of the disappeared frequently preserve childhood dental records, photographs of dental work, and occasionally extracted deciduous teeth as biological reference samples.

4.2.6 Dental Prosthetics, Implants, and Restorations as Forensic Identifiers

The forensic value of prosthodontic and restorative dental work extends beyond morphological matching to include material traceability. Each dental restoration embodies a temporal signature (materials used in specific eras can narrow the period of death), a geographic signature (specific materials or techniques were used in specific countries or regions), and in the case of dental implants, a manufacturer-encoded unique identifier accessible through CT imaging.

The first documented identification of a cremated unidentified individual through implant lot number recovery (Forensic Science International, 2026) establishes a new forensic paradigm: the dental prosthetic as coded biometric marker. The Straumann® implant system used in that case incorporates lot numbers traceable to specific manufacturing batches, enabling identification of the treating dental facility and, through clinic records, the patient identity. As dental implant prevalence continues to increase globally — projected to represent a multi-billion dollar market with millions of implant placements annually — this identification pathway will become progressively more valuable.

Khandelwal et al. (Cureus, 2025; PMC12143587) emphasised that titanium implants survive temperatures exceeding those of standard cremation, resist corrosion in soil and aquatic burial environments, and osseointegrate with alveolar bone in a manner that makes them highly resistant to displacement during taphonomic processes. The implication for the Mexican context — where bodies are found in varying states of carbonisation, burial, and dismemberment — is that implant-based identification represents a systematically underutilised identification pathway that should be integrated into SEMEFO examination protocols.

The figure 1 displays the annual accumulation of unidentified bodies registered in Mexican SEMEFO (forensic medical services) facilities between 2006 and 2019, based on the Quinto Elemento Lab – Crisis Forense public database (N = 32,022 records with valid registration year).

The trend is unmistakably exponential: from just 178 cases in 2006, the number escalated to 4,905 in 2019 — a 2,655% increase over 13 years, with a compound annual growth rate (CAGR) of 29.1%. The Pearson correlation between year and case volume is r = 0.943 ($p < 0.0001$), confirming a near-perfect linear growth trajectory.

Two critical inflection points are marked. The first occurs in 2009, where cases jumped 133% in a single year (from 620 to 1,443), directly coinciding with the military escalation of the Calderón administration's drug enforcement policy. The second occurs in 2016, reflecting renewed criminal territorial disputes following cartel fragmentation. From that point onward, annual figures never fell below 2,900 cases and reached their peak in the final year of the series.

The dashed line represents the linear trend, illustrating that growth was not episodic but sustained and structural throughout the entire period. Taken together, the figure provides stark quantitative evidence of a forensic system overwhelmed by an accelerating crisis — and establishes the empirical foundation for the argument that conventional identification methods are insufficient at this scale, making AI-augmented forensic dentistry a scientifically necessary and urgently required intervention.

Fig 1. Unidentified Bodies Registed per Year in Mexico (2006-2019)

The figure 2 combines two elements in one clean visualization: Stacked bars — blue (male), pink (female), gray (unknown sex) — showing the absolute volume and internal composition each year, with total labels at the top of each bar. Dashed orange line (right axis) — the male/female ratio per year, annotated at each point, revealing the extreme and persistent gender disparity throughout the entire period (ranging from 4.1x in 2006 to 14.8x in 2007)

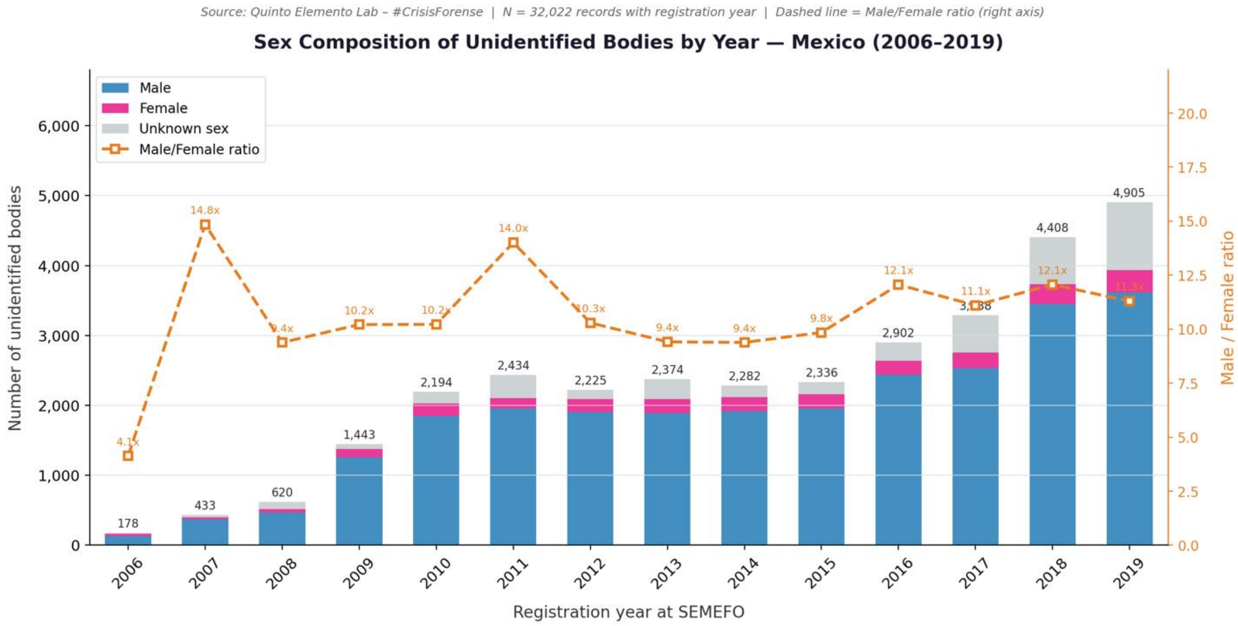

Fig 2 Sex Composition of Unidentified Bodies by Year – Mexico (2006 – 2019)

5. Discussion

5.1 Integration of Computational Findings and Forensic Dental Evidence

The convergence of the two analytical components of this study produces a coherent and scientifically compelling conclusion: Mexico's forensic identification crisis is numerically quantifiable, statistically characterised, and scientifically addressable. The crisis is not primarily a resource deficit — it is a technological, methodological, and institutional design failure.

The exponential growth in unidentified bodies (CAGR = 29.1%; $r = 0.943$) outpaced any plausible expansion of conventional identification capacity. The paradoxical decline in documentation quality as volume increased (Spearman $\rho = -0.626$; $p = 0.017$) demonstrates that scaling up conventional practice is insufficient; qualitative methodological transformation is required. The extreme heterogeneity across states — with Nuevo León achieving near-complete documentation while Veracruz and Guerrero record near-zero documentation — indicates that the problem is not uniformly distributed and that targeted intervention in high-volume, low-documentation states could yield disproportionate returns.

Against this backdrop, forensic odontology emerges as a uniquely suitable response technology. Its scientific characteristics — biological durability across all documented taphonomic conditions, morphological uniqueness, digital compatibility, and AI augmentability — precisely address the most severe technical constraints of the Mexican identification context: (1) the predominance of advanced taphonomic states due to prolonged burial and deliberate destruction of remains; (2) the absence of antemortem genetic reference samples for the majority of missing persons; (3) the institutional overload that renders manual case-by-case comparison impractical at scale; and (4) the geographic distribution of the crisis across 32 states with heterogeneous forensic capacity.

Despite these advantages, the practical implementation of forensic dental identification in Mexico remains constrained by fragmented antemortem record availability, heterogeneous documentation practices, and limited digital interoperability across jurisdictions. These barriers highlight the need for standardised data collection and integrated digital infrastructures capable of supporting large-scale forensic comparison.

5.2 Critical Methodological Assessment of the Crisis Forense Dataset

This study's engagement with the Quinto Elemento Lab dataset necessitates a frank methodological critique. While this dataset represents an extraordinary achievement in investigative transparency — the most comprehensive public documentation of Mexico's forensic crisis available — its scientific limitations must be acknowledged explicitly to avoid over-interpretation of quantitative findings.

The presence of 3,683 unique cause-of-death entries reflects the complete absence of standardised forensic cause-of-death coding across Mexican states. The absence of ICD-10 or equivalent encoding prevents epidemiological analysis of cause-of-death patterns and renders any classification system — including the one employed in this study — subject to unquantifiable classification error. The 'Ver base LG' references for 3,595 records represent information siloed in a companion database that was not integrated into the public release, creating structural incompleteness in the final disposition data.

The 17.7% rate of records without registration year, concentrated in specific states, raises the possibility that some records represent historical accumulations entered retrospectively rather than contemporaneous registration, potentially deflating volume estimates for certain years and inflating them for others. Finally, the dataset necessarily excludes bodies not reaching SEMEFO facilities: victims buried in clandestine graves not yet located, fragmented remains recovered as multiple separate cases, and individuals whose

disappearance was never formally reported — all of which are substantial in the Mexican context.
Despite these limitations, the dataset's N = 38,891 provides adequate statistical power for the principal analyses conducted, and the direction and magnitude of the major findings (exponential growth, documentation decline, geographic concentration, male predominance) are sufficiently robust to be interpretable despite the data quality constraints documented above.

5.3 The Case for a National Forensic Dental Database in Mexico

Mexico currently lacks a national forensic dental database (NFDD) capable of integrating antemortem dental records with postmortem dental findings. This absence represents a significant structural gap within the country's broader identification infrastructure. While forensic odontology should be understood as a complementary rather than a substitute identification modality alongside DNA analysis, fingerprint comparison, and forensic anthropology, its systematic integration could substantially expand identification capacity in a context characterised by large case volumes and heterogeneous forensic resources.
The scientific rationale for a NFDD is threefold. First, dental identification can proceed without biological reference samples from relatives, unlike DNA-based familial matching, which depends on the availability of suitable family reference samples. In many disappearance cases, relatives may be difficult to locate, unwilling to participate, deceased, geographically dispersed, or otherwise unavailable for genetic comparison, limiting the applicability of DNA-based approaches. However, forensic odontology faces a parallel challenge: the effectiveness of morphological dental comparison depends on the availability of antemortem dental records. In Mexico, these records are frequently incomplete, inaccessible, or unavailable due to variability in access to dental care, inconsistent record-keeping practices, patient mobility between providers, and the absence of systematic long-term preservation of clinical and radiographic documentation by both families and dental clinics. Consequently, the establishment of a national system for the collection, preservation, and digital integration of dental records is essential for maximising the identification potential of forensic odontology.
Second, digital dental records can be captured using equipment already present in many public and private dental practices, including panoramic radiography units, intraoral cameras, and increasingly digital imaging systems. This allows antemortem dental information to be collected without requiring highly specialised forensic infrastructure. Third, automated matching algorithms can process dental records at scales far exceeding manual expert comparison, directly addressing the volume challenge posed by Mexico's forensic identification crisis.
The operational model for a Mexican NFDD can draw on the NamUs system in the United States, which successfully integrates forensic odontology into its human identification infrastructure. Within that system, dental information from missing persons and unidentified human remains is digitally coded, uploaded, and compared by forensic odontologists affiliated with the programme. However, implementation in Mexico would require adaptations to the national context, including standardised protocols for postmortem dental examination in decomposed and skeletonised remains, training and certification of forensic odontologists across all 32 states, interoperability with existing forensic information systems, and AI-assisted automated first-pass matching to manage large case volumes.
Although the National Forensic Data Bank (BNDF), formally established in 2023, was designed to integrate forensic information at the national level, a dedicated forensic dental database and standardised dental information protocols have not yet been incorporated as core components of its operational architecture. The future integration of a NFDD within the BNDF could significantly strengthen Mexico's identification capabilities by providing a scalable, cost-effective, and scientifically validated complementary pathway for the identification of unidentified human remains.

5.4 Proposed Framework: DENTALID-MX

Based on the scientific evidence synthesised in this study, we propose DENTALID-MX, a national AI-augmented forensic dental identification framework designed to support large-scale human identification efforts in Mexico. The proposed system integrates contemporary forensic odontology, restorative dentistry, prosthodontics, dental imaging, implant traceability, and artificial intelligence into a unified national infrastructure capable of supporting both antemortem and postmortem data management.
Table 6 summarises the technical architecture of DENTALID-MX, including its principal operational components, the dental variables recorded, applicable international standards, and their corresponding forensic applications. The framework is designed to ensure interoperability with existing forensic information systems while maintaining compatibility with INTERPOL Disaster Victim Identification (DVI) protocols and contemporary digital dentistry workflows.

Table 6. Technical Architecture of the Proposed DENTALID-MX National Forensic Dental Identification Framework

System Component	Key Dental Variables	Standards / Protocols	Scientific Basis	Primary Forensic Application
Postmortem Dental Registry	Tooth presence/absence, crown and root morphology, restorations, prostheses, implants, anomalies, trauma	INTERPOL DVI Form F2; FDI notation	High biological durability and individual variation of dentition	Standardised postmortem dental profiling

Dental Imaging Repository	Panoramic dental radiographs (OPGs), periapical radiographs, bitewings, CBCT scans, intraoral photographs, 3D scans	INTERPOL DVI; DICOM standards	Reproducible comparison of anatomical and restorative features	AM/PM image comparison
Restorative Dentistry Registry	Crowns, bridges, veneers, inlays, onlays, endodontic treatments	FDI notation	Unique restorative treatment patterns accumulated throughout life	Individualisation through restorative history
Prosthodontic Identification Registry	Fixed prostheses, removable partial dentures, complete dentures, denture markings and repairs	Prosthodontic charting protocols	Distinctive prosthetic configurations and materials	Identification of partially and completely edentulous individuals
Implant Traceability Module	Implant manufacturer, model, dimensions, position, lot and serial numbers	Manufacturer databases; CBCT verification	Manufacturer-specific morphology and traceability	Implant-based identification
Dental Biometrics Module	Crown dimensions, root morphology, pulp chamber measurements, odontometric variables	Standardised odontometric protocols	Quantifiable interindividual dental variation	Biometric individualisation
Biological Profile Estimation Module	Dental age indicators, developmental stages, pulp-to-tooth ratios, sex estimation variables	Demirjian, Cameriere, CBCT-based protocols	Predictable developmental and morphological patterns	Age and sex estimation
Antemortem Record Collection System	Clinical records, radiographs, orthodontic records, prosthodontic documentation, implant records, intraoral scans	National AM data collection protocol	Availability of comparative reference information	Creation of reference database
AI Matching Engine	Morphological, restorative, prosthetic and radiographic signatures	Deep learning and CNN-based algorithms	Automated recognition of complex dental patterns	Large-scale AM/PM comparison
Quality Assurance and Audit Module	Verification metrics, confidence scores, audit trails, chain-of-custody documentation	ISO 17025 principles; forensic quality standards	Reproducibility and transparency	Legal defensibility
National Integration Platform	Cross-referencing with BNDF and other forensic repositories	Interoperability framework	Cross-system integration of forensic information	Nationwide identification workflow

The proposed architecture is organised around three complementary operational domains. First, data acquisition modules encompass postmortem dental examination, antemortem record collection, dental imaging, and the systematic recording of restorative, prosthodontic, and implant-related information. These modules create standardised digital records capable of capturing the individualising characteristics that make dentition one of the most powerful forensic identifiers.
Second, analytical modules integrate dental biometrics, biological profile estimation, implant traceability, and AI-assisted matching systems. By combining radiographic, morphological, restorative, and prosthetic information, the framework enables automated first-pass comparison of antemortem and postmortem records while preserving expert human verification. Finally, quality assurance and national interoperability modules provide auditability, legal defensibility, and integration with existing forensic infrastructures, including the National Forensic Data Bank (BNDF). Together, these components establish a scalable and technologically feasible identification framework that is compatible with current forensic practice and digital dentistry standards.
This framework is technologically feasible with current state-of-the-art AI systems, is cost-effective relative to mass genetic screening, and aligns with Mexico's existing legal framework under the Ley General en Materia de Desaparición Forzada de Personas (2017) and the mandates of the BNDF.

6. Public Policy Implications

The findings of this study have direct and urgent implications for forensic and human rights policy at both the national and international levels. We identify four priority policy domains.

6.1 Mandatory Forensic Dental Examination Protocols

All unidentified human remains processed through SEMEFO facilities should be subject to standardised postmortem dental examination regardless of decomposition state. Current SEMEFO protocols do not universally mandate dental examination, and the absence of forensic odontologists in most state-level facilities means that critical dental evidence is routinely lost when bodies are disposed to common graves without dental autopsy. The Ley General en Materia de Desaparición Forzada de Personas should be amended to explicitly require dental autopsy as part of the postmortem documentation protocol for all UHR.

6.2 National Forensic Dental Database (NFDD)

Mexico should establish a national forensic dental database as a component of the BNDF, with mandatory reporting by all dental practitioners for patients who subsequently disappear and voluntary antemortem record submission for missing persons. The database should follow INTERPOL DVI standards for dental data codification (F1/F2 forms), enabling international interoperability for cases involving migrants and cross-border disappearances.

6.3 Forensic Odontology Training and Deployment

A national programme for forensic odontology training should be established through a consortium of dental schools, forensic medicine institutes, and the UNAM forensic faculty. A minimum of one trained forensic odontologist should be available at each state-level SEMEFO facility. The existing network of dental schools across Mexico — including institutions in every state — provides a ready infrastructure for both training and capacity deployment.

6.4 International Human Rights Compliance

The identification crisis documented in this study constitutes a systematic violation of the right to truth and the right to identity under international law. The Inter-American Commission on Human Rights (IACHR) called in March 2023 for Mexico to develop a comprehensive national forensic policy. Implementation of the DENTALID-MX framework would represent concrete progress toward compliance with international human rights obligations and the principles of the International Convention for the Protection of All Persons from Enforced Disappearance.

7. Limitations

This study is subject to several limitations that constrain interpretation of its findings. First, the Crisis Forense dataset represents a partial and potentially biased sample of the true UHR burden in Mexico, as it is limited to bodies reaching SEMEFO facilities between 2006 and 2019 and relies on voluntary data provision by state-level authorities whose incentives for transparency vary. Second, the cause-of-death classification system developed in this study is heuristic and unvalidated; the proportion of misclassified cases is unknown but likely substantial. Third, cluster analysis was limited to the subset of states with sufficient complete data, excluding approximately 70% of records from the clustering analysis. Fourth, the literature review component, while comprehensive, is a narrative synthesis rather than a formal systematic review with meta-analysis; a future full systematic review with GRADE evidence assessment is warranted. Fifth, no primary forensic data (postmortem dental examinations, DNA results) was collected for this study; all findings are derived from secondary analysis of administrative records and the published literature.

8. Future Research Directions

Several high-priority research directions are identified by this study. First, a formal prospective validation study of AI-assisted dental identification in the Mexican forensic context is needed, applying CNN-based matching algorithms to a dataset of paired antemortem-postmortem dental records from identified cases. Second, a national survey of postmortem dental examination practices across Mexican SEMEFO facilities would establish the current baseline of forensic odontology integration. Third, population-specific forensic dental atlases should be developed for Mexican subpopulations, accounting for ancestry-specific dental morphology and the high prevalence of specific dental conditions and treatment patterns in different socioeconomic groups. Fourth, the feasibility of intraoral scanner deployment in mobile forensic units for field examination of remains in exhumation contexts should be assessed through a pilot study. Fifth, the specific contribution of mtDNA from dental cementum and dentin in Mexican taphonomic contexts (tropical soil chemistry, humid burial environments, high ambient temperatures) requires empirical investigation to validate extraction protocols developed in Northern European and North American contexts.

9. Conclusions

This study presents the first integrated analysis of Mexico's forensic identification crisis combining advanced computational methods with a systematic evidence synthesis of forensic dentistry as a scientific response paradigm. The principal conclusions are as follows.

The scale and trajectory of Mexico's unidentified body crisis is statistically extraordinary: 38,891 bodies registered between 2006 and 2019, with 29.1% compound annual growth and a systematic decline in documentation quality as volume increased. The extreme geographic concentration in seven states, the massive male predominance (ratio 10.7:1), and the overwhelming preponderance of common grave disposal collectively define a humanitarian crisis of the first order.

Forensic documentation failures are pervasive and systematic: 58.6% of records lack genetic profiles, 53.3% lack basic documentation files, 47.0% lack death certificates, and 17.7% lack registration years. The Forensic Documentation Index, though a necessarily simplified composite measure, demonstrates that approximately 43% of recorded bodies received fewer than two of four basic forensic documentation procedures.

Against this backdrop, forensic dentistry—supported by current artificial intelligence technologies—emerges as a scientifically robust, biologically resilient, and technologically scalable complementary modality for human identification. The exceptional durability of dental hard tissues across a wide range of taphonomic conditions encountered in the Mexican forensic context, including decomposition, carbonisation, skeletonisation, clandestine burial, and aquatic submersion, makes dentition one of the most durable and informative biological substrates available for identification. While the effectiveness of dental comparison depends on the availability and quality of antemortem records, advances in digital dentistry, CBCT imaging, 3D scanning, and AI-assisted pattern recognition have substantially expanded the identification potential of forensic odontology. Current AI systems achieve reported accuracies ranging from 85% to 99.1%, depending on the application domain, suggesting considerable potential for supporting large-scale antemortem/postmortem comparison workflows.

The DENTALID-MX framework proposed in this study outlines an implementable architecture for a national forensic dental identification system that is consistent with Mexico's existing legal framework, international human rights obligations, and the technical capabilities of contemporary forensic science and digital dentistry. However, the effectiveness of forensic odontology at scale depends on the systematic collection, preservation, and accessibility of antemortem dental records, highlighting the need for a National Forensic Dental Database and its future integration with broader forensic information systems, including the National Forensic Data Bank (BNDF). By combining forensic odontology, restorative and prosthodontic information, digital imaging, implant traceability, and artificial intelligence within a unified identification workflow, DENTALID-MX could substantially strengthen Mexico's human identification capacity and contribute to addressing one of the most severe forensic humanitarian crises currently documented in Latin America.

Data Availability

The public dataset analysed in Part I is freely available at: https://quintoelab.org/crisisforense/datos/ (Quinto Elemento Lab – #CrisisForense). All analysis code is available from the corresponding author upon reasonable request.

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