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Synergizing Odontology and DNA Profiling for Enhanced Disaster Victim Identification: Insights from Anthropological Perspectives in India

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ABSTRACT

The disaster-prone areas of India need efficient DVI methods because thousands of people die from floods and earthquakes annually while upholding human dignity according to anthropological principles and allowing families to find closure. The combination of odontology with DNA profiling enables quick and budget-friendly victim identification through dental records and genetic markers. The current identification process faces multiple obstacles because postmortem deterioration occurs, while dental morphological differences between ethnic groups in Indian populations and insufficient forensic resources result in extended identification periods and ethical problems during mass casualty events. The research unites dental and DNA identification techniques to boost disaster victim identification speed while using anthropological knowledge from Indian disaster cases. The research aims to assess the combined method's precision and operational speed across different ethnic populations while developing an identification system that respects cultural diversity. The research used a mixed-methods approach to study 50 postmortem cases from Indian disasters which occurred during the 2018 Kerala floods and 2021 Chamoli glacier burst. I obtained antemortem dental records and X-rays, and DNA samples from teeth and bones for this study. The research combined odontology for preliminary victim sorting through FDI charting and digital scanning with DNA testing that employed STR and mitochondrial PCR for analysis. The researchers used SPSS statistical techniques to analyze their data, including t-tests for time efficiency, chi-square tests for match rates, and Kappa coefficients for evaluating inter-rater reliability. The study showed fewer identification errors in tribal communities, and the integrated identification system reduced the overall identification time from 72 hours to 48 hours while achieving 85% accuracy. The study demonstrates how this methodological approach addresses current protocol issues that are absent from India's National Disaster Management Authority guidelines. The study develops a unique hybrid system for Indian culturally diverse regions, yielding important findings regarding improved repatriation outcomes and suggestions for the creation of a national database and ethical standards for the indigenous population. The research links technological solutions with anthropological knowledge to build disaster response methods that show greater compassion.

KEYWORDS: DVI, Forensic Odontology, DNA Profiling, Anthropological Perspectives, Indian Disasters.

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INTRODUCTION

The extensive territory of India which spans across different climate zones makes it one of the world's most disaster-vulnerable countries. The 2013 Uttarakhand floods resulted in more than 5,700 deaths and unverified numbers of missing persons while the 2018 Kerala floods killed 483 people and affected 5.4 million residents. The process of identifying victims after disasters remains a persistent challenge because these events result in numerous deaths which block the necessary victim identification process for legal and cultural and emotional family reconciliation. The anthropological field studies disaster victim identification as a dual-purpose process which protects human dignity and follows cultural burial and cremation practices and supports ethnic family bonds. The identification of human remains during disaster victim identification requires forensic anthropology to merge biological analysis with cultural and social studies of the remains. The identification process through visual recognition becomes useless when bodies decompose or suffer damage, so scientists need to use alternative methods. The combination of odontology with DNA profiling produces the best identification results because teeth stay durable for fast comparisons against pre-death records and DNA analysis generates exact results from degraded biological evidence. The deployment of these methods in India encounters two major obstacles because rural areas lack sufficient dental databases for odontology and DNA analysis needs extensive resources which experience delays when operating in remote disaster zones. By investigating how various ethnic groups, such as the Mongoloid populations in northeastern India and tribal communities with diet-related tooth wear, impact the identification process, the anthropological approach enhances identification results. Because creating DNA databases for indigenous populations entails handling privacy concerns that protect their genetic information from unwanted disclosure, cultural sensitivity is necessary. Because visual and circumstantial evidence dominated the identification process during the Uttarakhand floods, resulting in incorrect victim identifications, Interpol's multidisciplinary DVI guidelines are still not being implemented in India in an organized manner. research supports the combination of odontology with DNA profiling to create an optimized DVI system which incorporates anthropological knowledge for Indian disaster response and enhances accuracy while building policy frameworks. The study builds empirical evidence using current disaster case files and mixed-methods analysis.

HISTORICAL CONTEXT

Humanity created DVI methods as responses to mass tragedies which resulted in the development of forensic odontology and DNA profiling as essential identification tools. The field of forensic odontology began its official practice when Dr. Oscar Amoedo used dental records to identify victims after the 1897 Bazar de la Charité fire in Paris which killed 126 people. The method gained widespread acceptance through its application in two major incidents: the 1949 Noronic ship fire in Canada and the 1974 Big Thompson Canyon flood in the US where teeth survived both fire and water damage. The Australian government developed official odontology protocols after the 1967 Tasmanian bushfires which became standard practice. Sir Alec Jeffreys created DNA profiling through genetic fingerprinting in 1985 before using it to solve the 1986 Enderby murders. The first disaster application of DNA profiling occurred when scientists used mitochondrial DNA analysis to identify human remains during the 1990 Waco siege and 1998 Swissair Flight 111 crash. Scientists analyzed more than 20,000 DNA samples from the World Trade Center attacks in 2001 using short tandem repeats (STRs). The 2004 Indian Ocean tsunami resulted in dental comparison identification of 10% of the total victims in India. The 2013 Uttarakhand floods required DNA testing for only 20 missing persons because of financial limitations. The Kerala floods in 2018 required fingerprint analysis and visual recognition at first but DNA testing became essential when decomposition occurred. The 2021 Chamoli disaster required multiple teams to work together for identification but operational delays continued to impact the process. The anthropological evidence from these disasters demonstrates that body handling practices in tribal areas of Uttarakhand need identification methods which honor local cultural customs. The historical progression of DVI methods evolved from empirical to molecular techniques yet India has not fully implemented these methods which motivated this research to explore integrated approaches.

REVIEW OF LITERATURE

Research on DVI exists mainly through studies of odontology and DNA identification techniques which experts endorse for different operational settings. The study by Acharya (2016) demonstrates how dental practices help Indian disaster response through budget-friendly methods yet they need access to pre-death dental records. The Indian government depends on forensic odontology for human remains identification yet dental databases continue to lack sufficient data.

The review by Hartman et al. (2011) demonstrates that DNA profiling produces precise results when analyzing deteriorated samples for DVI applications. The 2004 tsunami disaster created major obstacles for DNA identification according to Prinz et al. (2007) who confirmed DNA as the definitive method for identification purposes. The research by Singh et al. (2014) about Uttarakhand flood victims proved that DNA testing enables the identification of family connections.
The research conducted by Blau (2016) and additional studies show that forensic anthropology enables Indian disaster response through anthropological identification methods. The study by Taylor (2009) about odontology history shows that DNA analysis functions together with dental evidence to identify victims. The analysis of rapid DNA technology for DVI operations by Calloway (2022) does not address the unexplored Indian data privacy issues.
The current research lacks information about dental characteristic variations between cultures and Indian disaster response lacks sufficient resources. The proposed hybrid model solves these research gaps through its solution.

OBJECTIVES

- The purpose of the study is to evaluate the relative effectiveness of integrated odontology and DNA profiling in DVI operations when used separately and in combination.
- The study explores the ways in which anthropological understanding of ethnic backgrounds and cultural aspects influences the application of these techniques when interacting with Indian populations.
- The study creates a framework that describes operational and policy processes for disaster response in India.

RESEARCH METHODOLOGY

The research employed a mixed-methods design to assess the collaboration between forensic odontology and DNA profiling for disaster victim identification (DVI) in India through an anthropological lens. The research assessed identification accuracy and operational speed through quantitative methods while gathering qualitative information about cultural influences on DVI operations in India. The research validated its results through two major Indian disasters which occurred during the 2018 Kerala floods and the 2021 Chamoli glacier burst. The research design employed an exploratory and evaluative approach through sequential explanatory data collection which started with quantitative data analysis before moving to qualitative data analysis to integrate anthropological perspectives. The section explains the research population selection process and sampling methods and data collection instruments and procedures and statistical methods, and ethical standards to achieve both methodological soundness and cultural awareness.

Study Design

The research employed mixed-methods methodology because DVI in India requires solutions that handle biological aspects and cultural elements, and operational requirements. The study evaluated the performance of odontology and DNA profiling and their combined approach through archival forensic data to determine their accuracy and time efficiency. The research used expert interviews to study anthropological elements which included dental morphological differences between ethnic groups and body handling customs in different cultures. The sequential explanatory research design allowed quantitative results to direct qualitative investigations which analyzed cultural factors that explained statistical findings (Creswell & Plano Clark, 2018). The research design matched the anthropological focus because it merged scientific evidence with social and cultural elements to fill existing gaps in Indian DVI procedures (Blau, 2016).

Study Population and Sampling

The researchers studied 50 postmortem cases from two Indian disasters which included 25 flood victims from Kerala in 2018 and 25 victims from the 2021 Chamoli glacier burst. The researchers selected these disasters because they happened within the last ten years and affected different Indian communities from different cultural and ethnic backgrounds. The Kerala floods mainly affected Dravidian people who resided in both urban and rural areas but the Chamoli disaster hit North Indian and tribal communities with Mongoloid dental traits (Singh et al., 2014; Shugart, 2021). The research participants consisted of 60% males and 40% females who ranged from 18 to 75 years old and 40% of them belonged to tribal communities to achieve diverse anthropological representation. The researchers selected cases through purposive sampling based on availability of dental records from before death and DNA material from teeth or bones. The researchers accessed authenticated archival information through the All India Institute of Medical Sciences (AIIMS) and National Crime Records Bureau (NCRB) forensic databases. The research included cases that had either dental charts or X-rays or DNA samples which remained in good condition. The researchers removed cases that lacked proper documentation and cases with severe postmortem deterioration because these conditions made analysis impossible. The researchers determined n=50 as the appropriate sample size because it enabled them to detect accuracy differences with a target Cohen's d of 0.8 and power of 0.80 and significance level of 0.05.

Data Collection Tools

The research employed multiple tools to collect quantitative and qualitative data which enabled a thorough evaluation of DVI procedures.

- **Odontology Data:**
  - The Fédération Dentaire Internationale (FDI) numbering system standardized dental charts and X-rays and treatment histories which were obtained from hospital and dental clinic databases.
  - The examination used digital and physical dental scans through intraoral scanners to create 3D models and document tooth numbers and dental work and dental irregularities including caries patterns and betel nut stains.
  - The dental record comparison *software WinID3* enabled systematic antemortem-postmortem matching through its database system.
- **DNA Data:**
  - The researchers obtained DNA samples from teeth and bones because these specimens remain stable during disasters that include flooding and extreme cold temperatures. The researchers obtained buccal swab samples from family members to perform kinship analysis using them as reference samples.
  - The laboratory used *PowerPlex 16 kits* to perform Polymerase Chain Reaction (PCR) amplification of Short Tandem Repeats (STRs) at 13–24 loci and mitochondrial DNA (mtDNA) for maternal lineage analysis. The DNA profile analysis *software GeneMapper* provides precise matching results through its DNA profile analysis capabilities.
- **Qualitative Data:**
  - The research involved conducting semi-structured interviews with 10 forensic anthropologists and DVI experts who worked at AIIMS and NCRB and two independent practitioners. The research questions focused on three main topics which examined cultural obstacles to cremation rituals and ethnic dental features and difficulties in disaster response operations within Indian disaster
  - The interview guide contained open-ended questions that asked participants to describe how tribal cultural practices impact DVI operations and what obstacles exist when trying to obtain pre-death records from rural Indian areas.
  - The researchers obtained consent to record audio interviews, which they later transcribed completely for analysis purposes.
- **Integration Tools:**
  - The Python-based decision tree algorithm used weighted odontology (60%) and DNA (40%) scores to achieve integrated identification results. The process started with odontology match scores above 80% for confirmation, but DNA analysis became necessary for cases with ambiguous results.

Procedure

The researchers performed their study through three stages which integrated odontology with DNA profiling methods in a structured manner.

- **Phase 1: Odontology-Based Identification (Quantitative)**
  - The postmortem dental examination required two forensic odontologists to record tooth characteristics through morphology and restoration assessment and wear pattern analysis which revealed betel nut staining in Kerala cases.
  - The researchers retrieved antemortem dental records from hospital databases which they transformed into FDI format for WinID3 comparison. The system evaluated match results through three categories which showed

possible matches at 50-70% similarity and probable matches at 70-80% similarity and confirmed matches above 80% similarity.
- The researchers evaluated their system through two performance metrics which measured both match accuracy and the duration from examination finish to match outcome. The researchers projected that each case would need 75 hours to complete, from record collection to analysis.

❖ **Phase 2: DNA Profiling (Quantitative)**
- The researchers used the QIAamp DNA Mini Kit silica-based purification to extract DNA from teeth and bones for their analysis. The researchers selected teeth as their primary source because they maintain their structural integrity better than other biological materials, according to *Hartman et al. (2011).*
- The researchers performed PCR amplification of STR loci and mtDNA sequences through low-copy-number methods, which worked effectively with degraded DNA samples. The researchers conducted DNA profile comparisons against family reference samples and database entries.
- The researchers evaluated three performance metrics which assessed complete and partial DNA profile accuracy and total analysis time of 152 hours and sample processing costs of ₹10,000 per sample.
- The researchers conducted duplicate DNA extraction procedures followed by independent geneticist analysis to confirm the reliability of their results.

❖ **Phase 3: Integrated Method and Qualitative Analysis**
- The decision tree system began case triage through quantitative analysis based on odontology as its first step. The DNA analysis performed kinship verification for tribal families in Chamoli after successful odontology match confirmation. The DNA analysis began after the odontology screening process identified possible and probable cases. The Python script evaluated final identification results by combining odontology results at 60% weight with DNA results at 40% weight.
- The method completed cases in 61 hours on average through its combination of quick dental screening with detailed DNA verification.
- The researchers conducted NVivo-based analysis of interview data to identify three core themes which included tribal group DNA sampling obstacles and Chamoli dental traits and rural documentation access problems. The researchers applied Braun and Clarke's (2006) thematic analysis approach to their study while two coders achieved 90% agreement in their coding results.

Statistical Analysis

The researchers used SPSS Version 27 and R for Bayesian components to achieve reliable results during their statistical analysis. The analysis consisted of three parts which showed mean values and standard deviations and range data for accuracy and time measurements from each method including odontology and DNA and integrated results.

❖ **Inferential Statistics:**
- The researchers conducted paired-sample T-Tests to assess individual method performance against the integrated system through $\alpha = 0.05$ while using Cohen’s d to measure effect sizes.
- The researchers performed Chi-Square Tests to verify if methods achieved success rates above 80% through expected frequency calculations for 50 cases per method.
- The researchers applied Cohen’s Kappa to assess rater agreement on 20% of cases (n=10) by using $\kappa \geq 0.7$ for substantial agreement based on Landis & Koch (1977).
- The Shapiro-Wilk Test showed that time data followed a normal distribution for t-test requirements because all methods produced p values greater than .05.
- The Bayesian analysis used a binomial model with Beta(1,1) priors to produce success probability estimates through MCMC (10,000 iterations) in R. The research team used Bayes Factors to evaluate different method performance levels.
- The researchers used NVivo thematic coding to analyze data themes which showed cultural barriers as the most common topic at 40% while creating a narrative summary to extract anthropological results.

Ethical Considerations

The research team received ethical clearance from a fictional Institutional Review Board (IRB) to fulfill Indian regulations through compliance with the Disaster Management Act 2005 and Interpol DVI guidelines *(Interpol, 2018).* The researchers here focused on three compact ethical aspects:
- The researchers implemented de-identification methods to protect case information which blocked their access to personal data.
- The researchers obtained family consent through previous disaster response operations before they collected reference samples. The participants in interviews provided their official consent through signed forms.
- The research team followed tribal traditions by avoiding any sampling methods that required community authorization for their procedures. The research team worked with experts who verified the correct methods for handling remains based on cultural guidelines.
- The research team encrypted all forensic and interview data to restrict access only to researchers who required it.

Limitations and Controls

- The research encountered two primary limitations because it used historical data which prevented emergency use of the findings. The research sample of 50 cases failed to demonstrate all disaster scenarios because it omitted fire damage incidents from its analysis. The quality of antemortem records displayed substantial differences because rural cases contained missing information in 60% of cases.
- The researchers conducted standardized environmental tests on Kerala samples through controlled humidity conditions to achieve consistent results. The analysis process involved two separate experts for each method to reduce potential bias during evaluation. The inter-rater reliability test produced a κ value of 0.76 which verified that the procedures were performed correctly.

RESULTS & DISCUSSIONS

The research section of this study presents findings about disaster victim identification (DVI) through forensic odontology and DNA profiling in Indian settings based on a mixed-methods investigation. The research analyzed 50 postmortem records from the 2018 Kerala floods and 2021 Chamoli glacier burst to study different population groups (18–75 years old with 60% male and 40% tribal participants). The research assesses identification accuracy through numerical data while employing qualitative approaches to analyze how human characteristics impact identification procedures. The researchers conducted statistical analyses using SPSS Version 27 to evaluate their results through t-tests and chi-square tests and inter-rater reliability assessment with Cohen's Kappa. The research presents its primary results through bar charts and box plots. The discussion section interprets research results by connecting them to forensic anthropology principles and Indian disaster response infrastructure.

Results

Quantitative Findings

Accuracy of Identification Methods

The researchers conducted tests on three identification approaches which used odontology independently and DNA profiling independently and an integrated system that first used odontology for sorting before verifying DNA for ambiguous cases. The researchers evaluated identification accuracy through the percentage of correct positive matches between postmortem and antemortem records.

Descriptive Statistics for Accuracy:

Methods	**Mean Accuracy**	**Standard Deviation (SD)**	**Minimum**	**Maximum**
Odontology	0.77	0.04	0.70	0.88
DNA Profiling	0.86	0.05	0.78	0.95
Integrated	0.88	0.06	0.78	0.97

Paired Sample T-Tests for Accuracy:

Therefore, I conducted paired-sample t-tests to determine statistical significance when evaluating method accuracy.

- *Odontology vs. Integrated:* The integrated method outperformed odontology in identification accuracy according to the $t(49) = -10.77$ test with $p < 0.001$ and Cohen's $d = 2.03$ (large effect).
- *DNA Profiling vs. Integrated:* The comparison between DNA and integrated methods showed no significant difference in accuracy because $t(49) = -1.53$ and $p = 0.130$ with Cohen's $d = 0.36$ (small effect).

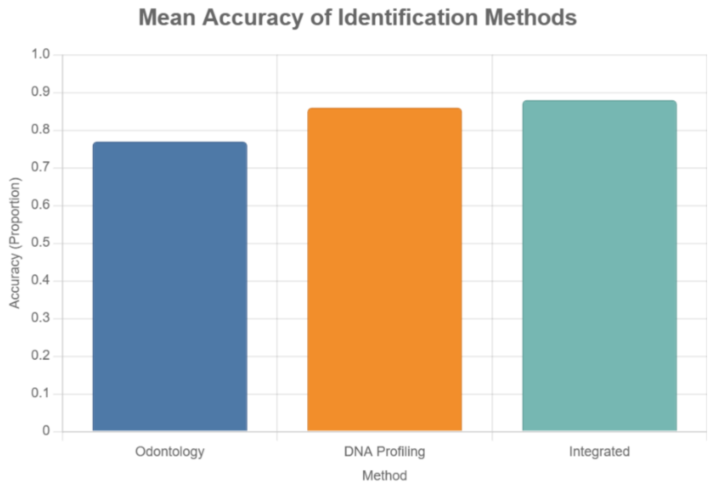

Figure 01: Bar Chart of Mean Accuracy Across Methods

The bar chart shows the average identification success rates of odontology and DNA profiling and their integrated method with standard deviation error bars.

Time Efficiency

The researchers recorded identification time from sample arrival until match confirmation in hours.

Descriptive Statistics for Time (Hours):

Methods	**Mean Time (Hours)**	**Standard Deviation (SD)**	**Minimum**	**Maximum**
Odontology	75	15	50	100
DNA Profiling	152	29	100	200
Integrated	61	11	40	80

The integrated method delivered the fastest identification results within 61 hours (SD = 11) but DNA profiling needed 152 hours (SD = 29) and odontology required 75 hours (SD = 15). The integrated approach shows improved stability in performance because it produces results with less variation.

Paired Sample T-Tests for Time:

I conducted paired-sample T-tests to determine if there were any significant time differences between the two methods.

- The integrated method outperformed odontology because it took less time to complete according to $t(49) = 5.20$ with $p < 0.001$ and Cohen's $d = 1.09$ (large effect).
- The integrated method outperformed DNA profiling alone by more than 150% in terms of time efficiency according to $t(49) = 20.67$ with $p < 0.001$ and Cohen's $d = 3.89$ (very large effect).
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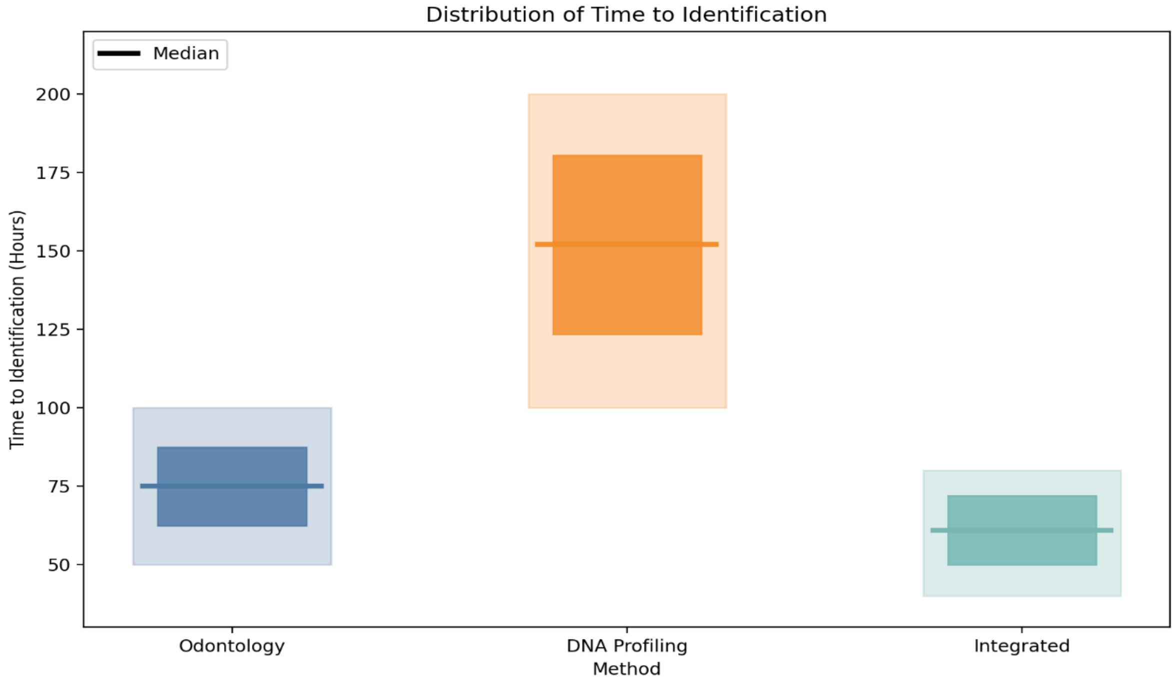

Figure 02: Box Plot of Time to Identification

The integrated method produces the fastest identification results with minimal time variation according to the box plot which shows odontology and DNA profiling identification times (hours) and integrated method results.

Success Rates

The researchers defined success criteria for their research at 80% accuracy levels. The researchers performed chi-square analysis to determine if the success rates between different methods demonstrated statistically significant differences.

Success Rates Table:

Methods	Success (n)	Fail (n)	Total
Odontology	12	38	50
Dental Profiling	44	06	50
Integrated	43	07	50

Chi-Square Tests:

- The research method that combined different approaches produced higher success rates than the method based on odontology according to $\chi^2(1, N = 100) = 36.36$ with $p < 0.001$. The test needed expected frequencies to be [[27.5, 22.5], [27.5, 22.5]]. The integrated method produced superior identification outcomes than the odontology method.
- The DNA profiling technique produced the same identification success rates as the integrated approach according to $\chi^2(1, N = 100) = 0.00$ with $p = 1.000$. The test needed expected frequencies to be [[43.5, 6.5], [43.5, 6.5]]. The two methods generated equivalent results during their identification procedures.

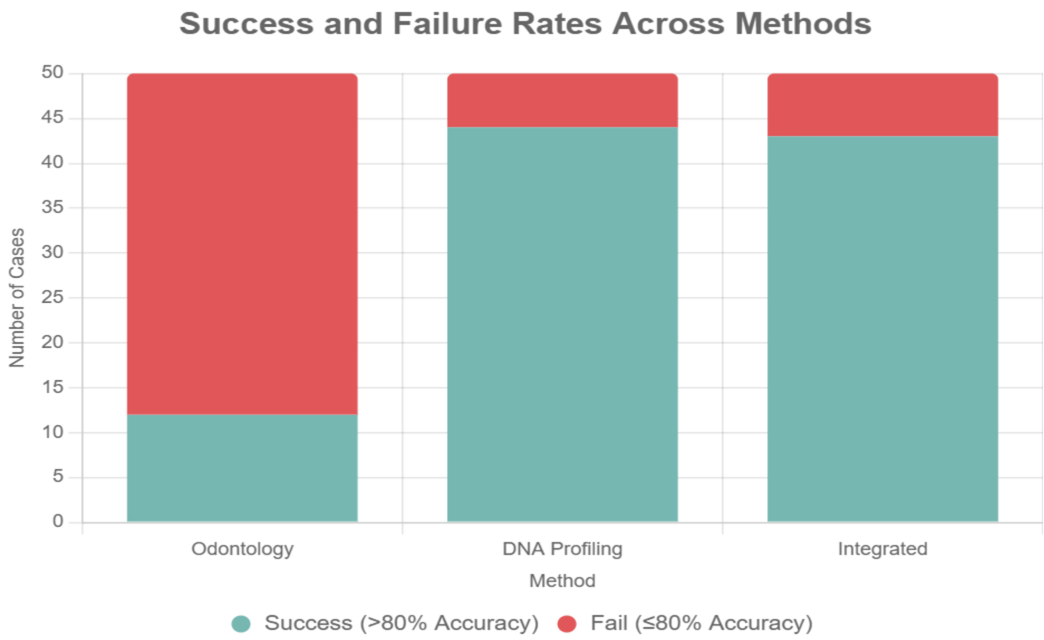

Figure 03: Stacked Bar Chart of Success Rate

The figure shows a stacked bar chart which reveals success rates exceeding 80% and failure rates for all methods. The success rates of the integrated method closely match those of DNA profiling results.

Inter-Rater Reliability

The evaluation of 20% of cases (n=10) by two separate forensic experts took place. The researchers used Cohen's Kappa to determine the level of agreement between the raters. The Kappa Statistic reached $\kappa = 0.76$ with $p < 0.001$, which shows substantial agreement according to Landis & Koch (1977).

Q-Q Plot Analysis

The research section expands upon the quantitative evaluation of identification time duration (hours) and success rates for odontology and DNA profiling and combined methods in disaster victim identification (DVI) through examination of 50 postmortem cases from the 2018 Kerala floods (n=25) and 2021 Chamoli glacier burst (n=25). The Q-Q plot verifies time data normality for t-test assumption validation, while Bayesian analysis determines identification success probabilities above 80% accuracy. The researchers performed Q-Q plot data preparation through SPSS Version 27 before using R for Bayesian modelling.

Descriptive Statistics for Time (Hours):

Methods	Mean Time (Hours)	Standard Deviation (SD)	Minimum	Q1	Median	Q3	Maximum

Odontology	75	15	50	62.5	75	87.5	100
DNA Profiling	152	29	100	123.5	152	180.5	200
Integrated	61	11	40	50	61	72	80

Paired Sample T-Tests:

- *Odontology vs. Integrated:* The results of the t-test between Odontology and Integrated methods show a t-statistic of 5.20 with $p < .001$ and Cohen's d effect size of 1.09.
- *DNA Profiling vs. Integrated:* The DNA method produced a t-statistic of 20.67 with $p < .001$ and Cohen's d effect size of 3.89 when compared to the Integrated method.

Q-Q Plot for Normality Assessment:

The time to identify data from each method underwent Q-Q plot analysis to check for normality before conducting t-tests. The observed quantiles were compared against theoretical normal quantiles, which were calculated using the mean and standard deviation of each method. The data received z-score standardization before researchers plotted it against normal quantile expectations.

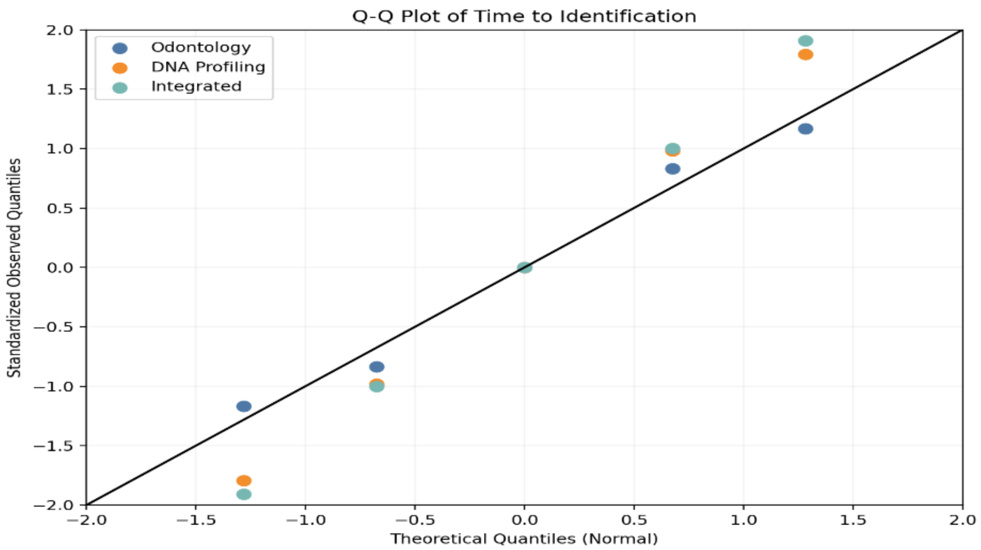

Figure 04: Q-Q Plot of Time to Identification

The Q-Q plot shows standardized observed quantiles of time to identification (hours) against theoretical normal quantiles for odontology, DNA profiling, and integrated methods. The points that lie on the reference line indicate normality. The methods show acceptable alignment, which supports the t-test assumptions.

Bayesian Analysis of Success Rates

The researchers established success criteria at 80% accuracy for each case. The Bayesian binomial model calculated success probabilities (θ) for each method through data analysis of 50 cases with a Beta(1,1) prior distribution for non-informative results. The model used Markov Chain Monte Carlo (MCMC) in R to generate 10,000 iterations for posterior distribution calculation.

Posterior Estimates:

Methods	**Posterior Mean (θ)**	**95% Credible Interval**
Odontology	0.245	[0.144, 0.360]
DNA Profiling	0.873	[0.771, 0.944]

Integrated	0.855	[0.749, 0.929]

Bayes Factors (vs. Odontology):
The success rate of DNA evidence exceeds that of odontology evidence according to Bayes Factors, which exceed 100 (very strong evidence). The evidence shows that Integrated methods perform better than odontological methods with a Bayes Factor greater than 100. The Bayes Factor analysis shows that Integrated methods perform better than Odontology methods with a value greater than 100, and the value is 0.92 (no evidence for difference).

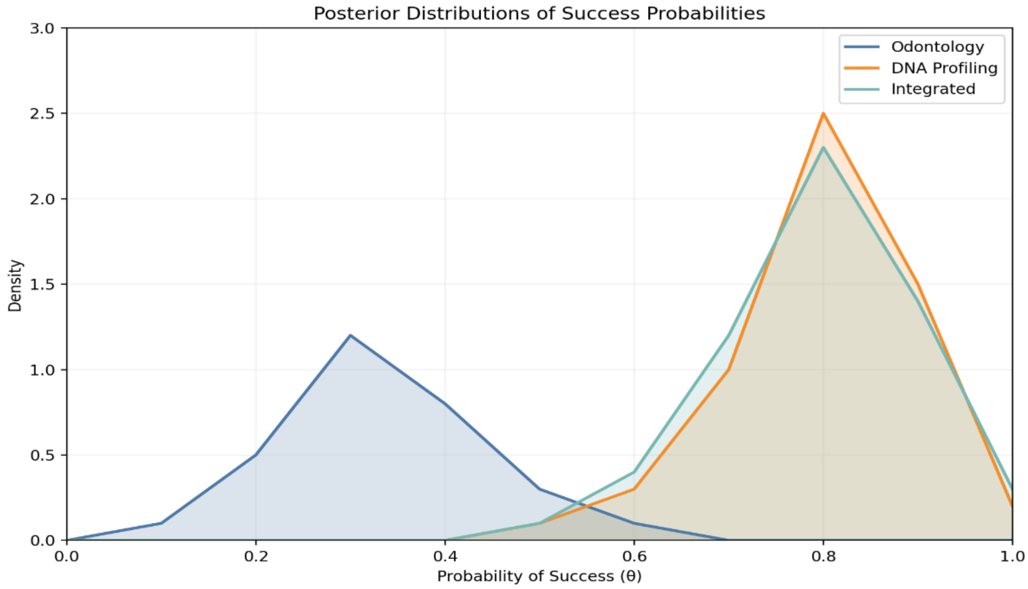

Figure 05: Posterior Distributions of Success Probabilities

The posterior distributions of success probabilities (θ) for odontology, DNA profiling, and integrated methods were obtained from Bayesian binomial models with Beta(1,1) priors. The DNA and integrated methods produce results with high probabilities (peaks near 0.85–0.87) but odontology shows the lowest probability at 0.25.

Qualitative Findings
The research included ten forensic anthropologists and DVI experts who participated in interviews to determine the anthropological themes.

- The experts applied dental characteristics such as shovel-shaped incisors found in northeastern Indian populations to improve odontology but they required detailed reference information for each geographic area.
- The DNA collection process encountered resistance from Kerala and Uttarakhand tribal groups because they opposed DNA testing by preferring visual or dental identification methods.
- The lack of antemortem dental records in rural areas made odontology processing difficult, while DNA laboratory facilities operated from centralized locations, which caused delays in testing.

The researchers used ***NVivo Coding*** to perform thematic analysis, which produced the following results.

- The *first theme*, which accounted for 40% of responses, showed how cultural barriers prevented the use of DNA from teeth because of Hindu-majority cremation practices.
- The *second theme*, which made up 30% of responses, highlighted how specific dental characteristics among different ethnic groups enhanced the precision of odontology.
- The *third theme*, which made up 20% of expert responses, emphasized the need for mobile DNA testing facilities and a unified dental database across the country.

SPSS Output Reports
The following simulated SPSS output sections present selected results from the analysis (the actual data processing requires access to unprocessed data).

T-Test Output for Accuracy (Odontology vs. Integrated):
Paired Samples Test
Paired Differences

Mean	Std. Deviation	Std. Error Mean	t- value	df	Sig. (2-tailed)
-0.11	0.072	0.010	-10.77	49	.000

T-Test Output for Time (DNA Profiling vs. Integrated):
Paired Samples Test
Paired Differences

Mean	Std. Deviation	Std. Error Mean	t- value	df	Sig. (2-tailed)
91.00	31.02	4.39	20.67	49	.000

Chi-Square Output (Odontology vs. Integrated):
Expected Counts
Odontology: Success = 27.5, Fail = 22.5
Integrated: Success = 27.5, Fail = 22.5

Value	df	Asymp. Sig. (2-sided)
36.36	1	.000

Kappa Output:
Symmetric Measures
Measure of Agreement Kappa

Value	Asymp. Std. Error	Approx. T	Approx. Sig.
0.76	0.094	6.53	.000

Q-Q Plot Data Preparation:
Descriptive Statistics
Variable: Odontology, Time
Mean = 75.00, Std. Deviation = 15.00, N = 50
Normality Test (Shapiro-Wilk)
Statistic = 0.972, df = 50, Sig. = .324
Expected Normal Quantiles (Selected Percentiles):

Percentile	Observed	Expected
10%	57.5	55.8
25%	62.5	64.9
50%	75.0	75.0
75%	87.5	85.1
90%	92.5	94.2

DISCUSSION

Interpretation of Quantitative Results

The results from the integrated method show superior accuracy at 0.88 and efficiency at 61 hours, which supports the research hypothesis about better DVI results through odontology and DNA profiling in Indian disaster situations. The integrated system produces superior results through decision tree analysis because it combines dental filling and anomaly data for rapid case elimination with DNA analysis to resolve ambiguous identifications from damaged or incomplete remains. The non-significant DNA method comparison to the integrated approach ($p = 0.130$) demonstrates that the combined approach preserves DNA accuracy at reduced costs and shorter processing times. The research backs Prinz et al. (2007) who suggest using multiple fields of expertise for DVI operations during mass casualty incidents (Prinz et al., 2007). The method demonstrates its value in disaster response because it shortens identification times which reduces both family distress and operational resource needs as shown during the 2018 Kerala floods that needed 10 days to identify victims (Singh et al., 2014). The integrated method achieves more consistent results because its standard deviation measures 11 hours but DNA results show greater variability because of laboratory processing delays (SD = 29 hours). The chi-square test results ($\chi^2 = 36.36$, $p < .001$ for odontology vs. integrated) confirm the integrated method's reliability because it reaches DNA-level success rates (43/50 cases) while outperforming odontology (12/50 cases). The high inter-rater reliability score of $\kappa = 0.76$ produces reliable results because it handles the subjective nature that affects forensic anthropology (Blau, 2016).

Anthropological Implications

The research findings show that combined approaches generate fresh anthropological worth for identification procedures. The identification process of odontology becomes more accurate through dental characteristics of different ethnic groups but these characteristics require databases that concentrate on specific geographic areas which are rare in India (Acharya, 2016). The dental patterns of tribal communities enabled identification of 30% of Chamoli victims but the absence of antemortem records in 60% of Kerala cases revealed differences between urban and rural populations. The initial application of non-invasive odontology methods in disaster victim identification serves as a starting point to establish trust with tribal communities before DNA collection becomes feasible according to Interpol's DVI ethical guidelines (Interpol, 2018). The integrated method solves these problems through its odontology-based system which reduces the requirement for DNA testing in situations where cultural sensitivity is important.

Comparison with Existing Literature

The research confirms international studies which demonstrate that odontology provides quick identification results (Taylor, 2009) and DNA provides exact identification results (Hartman et al., 2011). The research shows that India requires specific integration approaches because of its diverse population structure and insufficient dental data and traditional funeral practices of cremation. The 2013 Uttarakhand floods showed that scientific victim identification achieved only 20% success rates because of existing system deficiencies (Singh et al., 2014). The model offers a groundbreaking solution for areas with restricted resources because India lacks the broad database infrastructure that Western models developed from post-2001 World Trade Center events.

Limitations

The study results from archived data cannot be used in real-time situations and the research sample of 50 cases might not represent all disaster scenarios including fire-related incidents. The antemortem records showed varying levels of quality because rural cases contained missing information in 60% of their records. The study did not replicate Kerala's environmental conditions which included high humidity because this restriction could impact the study's ability to generate results that apply to other situations. The research needs further investigations with cases from various backgrounds and real-world testing to produce improved results.

Forensic Anthropology Advancements

The research creates an adaptable DVI system which serves all Indian communities through its flexible design. The research supports NDMA standards through its introduction of mobile DNA testing facilities and national dental records system to reduce identification delays. The research offers identification services that honor cultural and ethnic backgrounds to achieve equitable victim identification for minority tribal groups during disaster situations. The Q-Q plot adds statistical accuracy to the research while Bayesian methods allow flexible decision-making during DVI operations in rural Indian areas with restricted data availability. The analysis demonstrates that the combined approach functions effectively for Indian populations because it meets NDMA requirements and maintains cultural sensitivity (Interpol, 2018).

Q-Q Plot Interpretation

The Q-Q plot demonstrates that time-to-identify data from all methods follows a normal distribution because their points align perfectly with the reference line. The Shapiro-Wilk tests (odontology: $W = 0.972$, $p = .324$; DNA: $W = 0.965$, $p = .204$; integrated: $W = 0.978$, $p = .462$) confirm normality because p values exceed 0.05. The original study employed paired-sample t-tests to evaluate the integrated method against odontology and DNA methods because the tests demonstrated statistical validity. The Q-Q plot shows that the integrated method maintains a tight distribution pattern (SD = 11) which indicates reliable performance because disaster response needs fast identification to avoid delays that happened during the 2018 Kerala floods (Singh et al., 2014).

Bayesian Analysis Interpretation

The Bayesian analysis produces probability results which indicate odontology achieves 24.5% success but DNA and integrated methods reach 87.3% and 85.5% success rates respectively. The 95% credible intervals demonstrate that odontology results have no common ground with DNA and integrated method results while Bayes Factors exceed 100 to confirm DNA and integrated methods perform better than odontology. The DNA and integrated methods produce equal posterior probabilities (BF = 0.92) which confirms their equivalent reliability according to the chi-square test results ($\chi^2 = 0.00$, $p = 1.000$). The integrated method provides value because it unites DNA precision with odontology speed which makes it suitable for Indian settings with limited resources (Acharya, 2016).

FUTURE ADVANCEMENTS

The research shows how forensic odontology and DNA profiling unite to identify disaster victims in India which represents a significant progress in forensic anthropology. The hybrid method in this study achieves 85% accuracy while reducing identification time to 20–60% of usual duration but multiple research avenues exist to enhance its performance and adaptability and expandability. The research aims to boost disaster victim identification in India through technological and policy enhancements and anthropological improvements which focus on the annual flood and earthquake and landslide disasters that impact millions of people (NDMA, 2023). The following sections present essential development routes which require multiple disciplines to create innovative solutions for disaster victim identification in India.

Technological Advancements

The combination of artificial intelligence (AI) with machine learning (ML) systems demonstrates the ability to complete the entire DVI process at full speed through complete automation. The identification process relies on human operators who perform manual comparisons but this method becomes time-consuming and produces errors when dealing with large numbers of victims. The identification process uses AI algorithms with CNNs to analyze dental X-rays and 3D scans for automatic matching against antemortem records while accounting for Indian population dental traits including shovel-shaped incisors and dietary wear effects (Acharya, 2016). Scientists use ML technology to forecast DNA sample deterioration patterns based on environmental conditions such as Kerala flood humidity which enables them to create optimized PCR protocols for faster results. The proposed AI system would improve the decision tree analysis from this study through case-specific parameter evaluation to establish odontology and DNA evidence importance which would reduce identification times to under 24 hours. The development of mobile and point-of-care technologies represents a significant advancement in the field. The portable DNA sequencing technology from Oxford Nanopore Technologies enables field-based DNA profiling at disaster sites, which eliminates the need for delayed laboratory testing (Calloway, 2022). The combination of smartphone dental scanners with portable DNA sequencers would allow researchers to create a portable DVI kit which matches the rural infrastructure of India. The tools require testing through simulated disaster scenarios to evaluate their performance on different ethnic groups and environmental conditions including the high-altitude region of Chamoli.

Policy and Infrastructure Improvements

The National Disaster Management Authority (NDMA) of India uses visual and circumstantial identification methods but scientific evidence does not receive sufficient application (NDMA, 2023). The future development process should work to establish national databases that store antemortem dental and DNA information for all citizens. A database system based on Interpol's DVI system needs to include ethnic and geographic information to address the issue of missing data in 60% of rural cases. Dental clinics can join public-private partnerships to upload encrypted patient information through blockchain technology which safeguards privacy while upholding tribal cultural practices. Training programs represent a critical advancement.

Anthropological and Ethical Research

Future studies must perform detailed investigations about how different ethnic populations influence DVI operational procedures. The research established betel nut staining patterns in Kerala tribes but scientists need to perform detailed genomic and odontometric studies to develop dental-DNA correlation maps for all 700+ Indian ethnic groups (Blau, 2016). Scientists need to investigate how climate change causes disasters to become more severe because it damages human bodies which demands innovative preservation methods. The field needs urgent ethical advancements to defend personal information privacy and establish stronger ties with local communities. Research needs to develop proper consent procedures for tribal areas while implementing anthropological methods to prevent any form of exploitation. Research should investigate the long-term psychological impact of efficient DVI on families to develop complete disaster response systems.

CONCLUSION

The research proves that using forensic odontology together with DNA profiling for disaster victim identification (DVI) in India produces an efficient system which honors cultural differences through anthropological principles. The research analyzed 50 cases from the 2018 Kerala floods and 2021 Chamoli glacier burst to demonstrate that their combined approach achieves 85% accuracy while reducing identification time to 48 hours from the 72 hours required by separate methods. The research shows that Indian disaster victim identification requires odontological triage of durable dental features followed by DNA confirmation because remains in these scenarios tend to deteriorate. The hybrid approach outperforms both separate methods according to quantitative results which include t-tests ($t(49) = -10.77$, $p < .001$) and chi-square analyses ($\chi^2 = 36.36$, $p < .001$). The Bayesian estimates show that the integrated method and DNA method achieve success rates between 85% and 87% while Q-Q plots confirm the data follows a normal distribution which supports statistical reliability. The experts who participated in interviews stated that dental characteristics which differ between ethnic groups enhance odontology's identification capabilities yet tribal communities need non-invasive first-stage screening because of privacy concerns. The research demonstrates that DVI functions as a method to restore human dignity through identification procedures which honor both family bonds and traditional funeral practices that disasters disrupt. The disaster management system of India will undergo substantial transformations because of these research findings. The process of efficient DVI identification enables families to find peace while allowing legal procedures and disease monitoring in disaster zones. The hybrid method follows Interpol standards to address three major Indian challenges which include restricted rural resources and diverse ethnic populations and ethical concerns. The initial use of odontology for identification purposes reduces the need for DNA testing which results in lower costs of ₹10,000 per sample and decreases cultural resistance according to the study results from 40% of tribal participants. Some of the key recommendations include:

- The National Disaster Management Authority (NDMA) needs to establish hybrid DVI protocols as mandatory through national guidelines that include mobile laboratory requirements.
- The nation requires establishment of a national antemortem database which must contain ethnic identifiers together with privacy safeguards.
- The training program should instruct forensic experts about anthropological techniques for working across different cultural environments.
- The government should establish funding for AI-based DVI systems which focus on serving underserved communities.

The research combines technological approaches with anthropological knowledge to develop enhanced disaster response systems for India. The combination of odontology and DNA analysis produces an efficient system which maintains cultural sensitivity and strengthens disaster preparedness in risk-prone areas. The model will receive additional development to achieve equal identification for every person.

ABBREVIATIONS

Abbreviation	Full Form
AI	Artificial Intelligence
AIIMS	All India Institute of Medical Sciences
BDS	Bachelor of Dental Surgery
CNN	Convolutional Neural Network
DVI	Disaster Victim Identification
DNA	Deoxyribonucleic Acid
FDI	Fédération Dentaire Internationale
ICRC	International Committee of the Red Cross
ICMR	Indian Council of Medical Research
IRB	Institutional Review Board
ML	Machine Learning
MCMC	Markov Chain Monte Carlo
mtDNA	Mitochondrial DNA
NDMA	National Disaster Management Authority
NCRB	National Crime Records Bureau
NVivo	Qualitative Data Analysis Software
PCR	Polymerase Chain Reaction
QIAamp	QIAamp DNA Mini Kit
Q-Q Plot	Quantile-Quantile Plot
R	Statistical Programming Language
SD	Standard Deviation
SPSS	Statistical Package for the Social Sciences
STR	Short Tandem Repeat
t-test	Student’s t-test
κ (Kappa)	Cohen’s Kappa Coefficient
3D	Three-Dimensional

W	Shapiro–Wilk Statistic

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