Original Article

From teeth to ethnicity: A neural network approach to predicting population of origin through dental traits and anomalies

Suraj Kataria[1], Rohan Shinkre[2], Sonal Jain[3], Kallur Nava Saraswathy[3], Mohinder Pal Sachdeva[3], Mohan Kumar KP[4]

[1]Department of Forensic Sciences, School of Basic and Applied Sciences, K.R. Mangalam University, Gurugram, Haryana, [2]Central Research Wing, KLE Society's Institute of Dental Sciences, Bengaluru, Karnataka, [3]Department of Anthropology, University of Delhi, Delhi, [4]Department of Oral Pathology and Microbiology, College of Dental Sciences, Davangere, Karnataka, India

Abstract

Background: This study aimed to investigate the prevalence of dental traits and anomalies in five North Indian populations (Khas Bodhi, Jaat, Khatri, Garhwali, and Gujjar) and predict the population of origin based on these traits and anomalies for forensic applications.

Methods: We assessed dental traits and anomalies in 454 individuals through intraoral examination. Neural network analysis was employed to predict the population of origin based on a combination of dental traits and anomalies.

Results: Shovel-shaped incisors exhibited the highest prevalence among the studied traits and anomalies, occurring in 65.4% of the sample. Moreover, shovel-shaped incisors were found to be the most important predictor of population. Neural network analysis indicated that the most accurate population prediction among the studied populations was for the Garhwali origin, achieving a recall rate of 78.3%. While this may appear relatively low, it is crucial to emphasise that the proposed method serves as a corroborative tool for various forensic investigations.

Conclusion: This study suggests that dental traits and anomalies can be valuable in predicting the population of origin within Indian populations for forensic purposes. The work enhances the forensic identification process by providing an additional layer of evidence for consideration in identifying both individuals and their ethnic backgrounds. Further research is necessary to enhance the robustness of prediction models.

Keywords: Cusp of Carabelli, dental anomalies, dental traits, forensic odontology, neural network analysis, population prediction, shovel-shaped incisors

Address for correspondence: Dr. Mohan Kumar KP, Department of Oral Pathology and Microbiology, College of Dental Sciences, Davangere, Karnataka, India.
E-mail: drmohankp@gmail.com

Submitted: 24-Dec-2023, **Revised:** 04-Aug-2024, **Accepted:** 12-Aug-2024, **Published:** 15-Oct-2024

INTRODUCTION

The principal use of forensic odontology is the identification of human remains using the distinctive features present in human teeth.[1] When highly dismembered and mutilated dead bodies are recovered that are beyond recognition following disasters such as landslides, tsunamis, bomb blasts, airplane crashes, earthquakes, terrorist attacks, and road and train accidents, odontological evidence plays a critical role in identification.[2,3] Teeth, being the hardest organ in the human body, usually remain unaffected during

Access this article online

Quick Response Code:

Website:
https://journals.lww.com/JPAT/

DOI:
10.4103/jomfp.jomfp_546_23

How to cite this article: Kataria S, Shinkre R, Jain S, Saraswathy KN, Sachdeva MP, Kumar KP. From teeth to ethnicity: A neural network approach to predicting population of origin through dental traits and anomalies. J Oral Maxillofac Pathol 2024;28:515-25.

such catastrophes.[4,5] Each tooth has distinctive class characteristics that help broadly classify individuals. Studies have revealed that teeth class characteristics are useful in determining age, sex, ancestry or ethnicity, and profession, among other traits.[6] In addition, the diverse shapes, sizes, and gaps between the incisors, canines, premolars, and molars that constitute the adult human dentition form individual characteristics and serve as the foundation for personal identification among individuals.[7] Other features that aid identification include dental disease, restorations, and dental anomalies.[8]

The information obtained from dental traits and anomalies can be utilised to narrow down the search by estimating an individual's ancestry. Dental traits, including the scooping or shovelling of the upper incisor (particularly frequent among Amerindians and Asians), peg-shaped teeth, chisel-shaped incisors, taurodontism, protostylid, and Carabelli's cusp (as an essential marker of European ancestry), can be used to identify an individual's ethnicity.[9–12] Dental traits and anomalies have several etiologic origins, including genetic, epigenetic, and environmental.[13] Deciduous and permanent dentition can both be impacted by factors that may start before or after birth.[13] Ethnic variations were emphasised as a potential primary explanation for this diversity as different studies indicate varying frequencies of dental traits and anomalies in different ancestries.[9–12] Indian populations are divided into several castes, tribes, and religious groups. Rigid socioreligious borders, stringent endogamy practices, and evolutionary processes have all added to the already abundant, high-level diversity.[14] The complex genetic origin coupled with diverse sociocultural practices, and dietary patterns makes Indian populations intriguing candidates for studies on dental diversity and anomalies. Despite the high level of diversity in the prevalence of dental anomalies in different regions and populations of India, it is somewhat surprising that only a limited number of studies have attempted to capture the population-specific prevalence of dental traits and anomalies.[15–17] Considering this research gap, the present study aims to estimate the prevalence and patterns of dental traits and anomalies in five North Indian populations (Khas Bodhi of Himachal Pradesh, Jaat of Haryana, Khatri of Punjab, Garhwali of Uttarakhand, and Gujjar of Uttar Pradesh).

With respect to personal identification, the present study explores dental traits and anomalies based on neural network analysis to predict the population of origin. Neural network analysis offers greater predictive potential than traditional analytic approaches such as multiple regression from a methodological standpoint.[18] It is an effort to reduce prediction error and improve model accuracy. Neural networks have previously been used effectively to identify underlying trends in challenging datasets. Neural networks typically have separate layers; the input layer is the first and contains the dependent variables. Each variable is linked to a middle layer by an optimal number of 'nodes', each connecting all inputs to the next layer, which houses the chosen output variable. Neural networks often try to minimise the inaccuracy in output estimations throughout the learning phase by methodically improving the interconnecting weights between the network's nodes.[19] Neural networks have been explored and used in various forensic applications, such as age prediction through DNA methylation analysis.[20,21] To reiterate, the present study aims to estimate the prevalence and patterns of dental traits and anomalies and predict the population of origin based on dental traits and anomalies for forensic and anthropological purposes.

METHODS

Study design and participants

For the present population-based cross-sectional study, 454 participants (140 females) aged 18–35 years belonging to five North Indian populations were recruited from their native states by using convenience sampling. Of the recruited participants, 85 were Khas Bodhi of Himachal Pradesh, 74 were Jaat of Haryana, 105 were Khatri of Punjab, 99 were Garhwali of Uttarakhand, and 91 were Gujjar of Uttar Pradesh. All the recruited participants were healthy (having no self-reported physical or mental illness). Individuals with caries-affected teeth, cleft lips and palates, Down syndrome, ectodermal dysplasia, and those who received orthodontic treatment and did not consent to the study were excluded from the research. The study was conducted in accordance with the STROBE guidelines. Ethical clearances for the study were obtained from the Departmental Ethics Committee, Department of Anthropology, University of Delhi (ethical clearance ref no.: Anth/2021-22/07/002). Informed written consent, typed in the local language, was obtained from each participant before recruitment.

Sample size calculation

The minimum sample required for this study was estimated to be 357, based on observations reported by Patil *et al*.,[22] wherein the prevalence of dental anomalies in a North Indian population was found to be 36.7%, with the margin of error (d) taken as 0.05. With an additional margin of 25%, the calculated sample size was 447. Finally, in total, 454 individuals were recruited.

Training and calibration

A pilot study was conducted on the same population in the aforementioned geographical areas. The number of participants was limited to around 10% of the estimated sample size. In the pilot study, two dentists (R.S. and M.K.KP.) were trained to identify the dental anomalies and traits by using the criteria mentioned in Table 1 by an experienced Oral Medicine and Diagnostic Specialist. In case of any discrepancies, his opinion was deemed decisive for anomaly identification. Following dental anomalies were assessed: Talon's cusp, macrodontia, microdontia (peg-lateral incisors), amelogenesis imperfecta (AI), dentinogenesis imperfecta (DI), hypodontia/anodontia, hyperdontia (mesiodens and supernumerary teeth [excluding mesiodens]), transposed teeth, crowding, and midline diastema. Apart from dental anomalies, dental morphological traits, including shovel-shaped incisors and the cusp of Carabelli, were assessed. The inter-examiner reliability was determined to be 0.92, demonstrating excellent internal consistency at a 95% confidence interval. These subjects assessed in the pilot study were not included in the final study.

Data collection

Data were collected with the aid of community-based dental health camps organised by collaborations with local NGOs that conducted dental screening procedures in a mobile dental van (MDV). MDV programs are a part of dental initiatives developed and implemented in India by institutions and organisations that provide dental care to neglected, underserved, and isolated rural areas through dental camps. These vans include dental machinery and equipment, are completely furnished, and house a waiting area.[37] Data related to sociodemographic variables such as age, sex, and community were collected from each participant by using a modified interview schedule and birth certificates. A comprehensive medical and dental history was taken by the examiners. Dental hard-tissue traits and anomalies were visually examined on the field in the MDV. The intra-oral examination was done visually with a sterilised mouth mirror and dental explorer using light from the dental chair in the MDV (Dunning Type III examination). Before examining each tooth, loose intra-oral debris was removed, and the teeth were dried using gauze. Participants who were found to have dental anomalies that needed radiological confirmation for a conclusive diagnosis were required to take an intra-oral peri-apical (IOPA) at the discretion of the examiners.

Statistical analysis

Statistical analysis was done using SPSS version 28 and MS Excel 10. The overall and population-wise prevalence of

Table 1: Diagnostic criteria of various dental traits and anomalies taken in the study:

Dental traits and anomalies	Diagnostic criteria	References
Talon's cusp	Talon's cusp was diagnosed when an accessory cusp was observed in the form of a cingulum close to the cementoenamel junction on the lingual surface of anterior teeth (0=absence; type I–III=presence)	[23]
Shovel-shaped incisors	Shovel-shaped incisors were diagnosed when the palatal/lingual surface of upper and lower anterior teeth was surrounded by a clearly defined raised mesial and distal enamel border forming a hollow area (as per ASUDAS: 0=absence; 1–7=presence).	[24]
Cusp of Carabelli	The cusp of Carabelli was diagnosed when a tubercle was observed on the palatal surface of the mesiopalatal cusp of permanent maxillary I-Molar (as per ASUDAS: 0=absence; 1–7=presence).	[25]
Macrodontia	Macrodontia was diagnosed when a tooth was abnormally large compared to its antimere.	[26]
Peg lateral (microdontia)	Peg lateral incisors (a form of localised microdontia) were diagnosed as those maxillary lateral incisors with no incisal edge on the occluding surface and a cone-shaped crown.	[27]
Amelogenesis imperfecta (AI)	The AI was diagnosed when the teeth involved appeared discoloured, prone to disintegration or sensitive, pitted, and the enamel appeared hypomineralised, hypoplastic, or both. (As per Witkop: 0=absence; type I–IV=presence)	[28]
Dentinogenesis imperfecta (DI)	The DI was diagnosed when the teeth involved appeared grey to yellowish-brown in colour, had wide crowns, and constriction in the cervical region that gave the teeth a 'tulip' form (as per Shields: 0=absence; type I–III=presence).	[29]
Hypodontia/anodontia	Hypodontia/anodontia was diagnosed when one or more teeth were absent (0=absence; 1=presence. (Exclusion criteria: missing third molar, tooth extracted during caries, orthodontic treatment, or trauma)	[30]
Mesiodens	Mesiodens was diagnosed when a supernumerary tooth was present between upper central incisors in the midline.	[31]
Supernumerary tooth	The supernumerary tooth was diagnosed when an increased number of teeth was observed in addition to the normal complement. (Exclusion criteria: mesiodens; inclusion criteria: paramolars, parapremolars)	[32]
Transposed teeth	Transposed teeth were diagnosed when an interchange between two adjoining teeth was observed in the same quadrant of the dental arch.	[33]
Dental crowding	Dental crowding was diagnosed when there was a disparity between the teeth size and the arch's dimensions, leading to a malocclusion.	[34]
Midline diastema	Midline diastema was diagnosed when a gap was observed between maxillary or mandibular central incisors (0=no diastema [space <0.5 mm]; 1=diastema [space>0.5 mm]).	[35]
Dens evaginatus	Dens evaginatus was diagnosed when an odontomere or tubercle was observed on the central sulcus of upper or lower premolars (0=absence; 1=presence).	[36]

*ASUDAS: Arizona State University Dental Anthropology System each dental trait and anomaly were determined. Chi-square tests ($\chi 2$) were used to determine significant differences in the frequency distribution of various dental traits and anomalies. A *P* value of <0.05 was considered statistically significant for all the statistical analyses.

Neural network analysis was employed to predict the population of origin by using a combination of dental traits and anomalies.[20] The input features for the neural network model were the dental traits and anomalies, represented as specific terms. The neural network architecture consisted of a single hidden layer containing eight units. The activation function used within this hidden layer is the hyperbolic tangent (tanh), chosen for its ability to capture complex nonlinear relationships in the data. The output layer responsible for producing predictions employed an identity activation function. The output received was the prediction of five populations by using dental traits and anomalies (the inputs). To ensure the robustness and generalisation capability of our model, we partitioned the dataset into two distinct sets: a training set and a test set. Specifically, 70% of the data was allocated for training, while the remaining 30% was reserved for testing. The training process of our neural network employed the batch method. This approach updates the model's weights after processing the entire training dataset, which can lead to more stable convergence and improved accuracy. The detailed network information is provided in Table 2.

We fine-tuned our neural network using the scaled conjugate gradient optimisation algorithm. This choice was based on its effectiveness in optimising neural network weights, making it suitable for our prediction task. The effectiveness of our model was further refined by specifying key training options, including an initial Lambda value of 0.0000005, an initial Sigma value of 0.00005, an interval centre set at 0, and an interval offset of ±0.5.

Common metrics employed for evaluating the performance of our classification models were accuracy, precision, and recall. Accuracy serves as an overarching measure of the model's correctness and is calculated by dividing the number of correctly predicted instances (TP + TN) by the total number of instances in the dataset (TP + TN + FP + FN). Precision, on the contrary, focuses on the accuracy of positive predictions, calculated as the ratio of TP to the sum of TP and FP. Recall (also known as sensitivity or TP rate) assesses the model's ability to correctly identify actual positive instances, determined by the ratio of TP to the sum of TP and FN. In our calculations, TP represents true positives, TN represents true negatives, FP represents false positives, and FN represents false negatives. These metrics collectively provide a comprehensive evaluation of our classification model's performance. In the present study, we considered recall percentage as a key performance metric. This choice is supported by the nature of the classification task, where the identification of all TP instances holds more importance. High recall, by design, minimises the risk of missing critical instances within the dataset. This aligns perfectly with our objective of comprehensive positive class detection. In situations where the cost of FN is high, focusing on recall ensures a more accurate and effective model performance assessment.

Table 2: The network information used in the neural network model

Layer type	Parameters	Details
Input layer	Factors	1. Talon's cusp 2. Shovel-shaped incisors 3. Cusp of Carabelli 4. Macrodontia 5. Peg lateral (microdontia) 6. Amelogenesis imperfecta (AI) 7. Dentinogenesis imperfecta (DI) 8. Hypodontia/anodontia 9. Mesiodens 10. Supernumerary tooth 11. Transposed teeth 12. Dental crowding 13. Midline diastema 14. Dens evaginatus
	Number of units	28
Hidden layer (s)	Number of hidden layers	1
	Number of units in the hidden layer	8
	Activation function	Hyperbolic tangent
Output layer	Dependent variables	Population of origin (Khas Bodhi, Jaat, Khatri, Garhwali, and Gujjar)
	Number of units	5
	Activation function	Identity
	Error function	Sum of squares

RESULTS

Prevalence of dental traits and anomalies in the study sample

The present study comprised 314 males (69.16%) and 140 females (30.83%). The mean age of the overall sample, males, and females was 25.47 ± 5.45, 25.39 ± 5.32, and 25.64 ± 5.74, respectively. The minimum age of the overall sample was 18 years, and the maximum age was 35 years. The prevalence of dental traits and anomalies in the overall sample, and also among male and female participants, were found to be 86.34% (392/454 individuals), 88.85% (279/314 individuals), and 80.71% (113/140 individuals), respectively. The prevalence of each dental trait and anomaly in the overall sample is represented in Table 3.

The prevalence of shovel-shaped incisors was the highest (65.4%) among the studied traits and anomalies, followed by teeth crowding (26.4%) and the cusp of Carabelli (23.6%). The prevalence of DI was the lowest (0.2%). Among the anomalies of shape and size, the prevalence of Talon's cusp was 2%, dens evaginatus (DE) was 3.5%, peg lateral was 4%, and macrodontia was 0.4%. The prevalence of AI was 0.4% among the anomalies of structure. Among the anomalies of number, the prevalence of hypodontia/anodontia was 4%, mesiodens was 1.1%, and supernumerary/hyperdontia was 1.8%. Among the anomalies of position, the prevalence of transposed tooth and diastema was 0.7% and 15.9%, respectively. Workflow illustrating steps from data collection to result interpretation in predicting population of origin in given in Figure 1.

PREDICTING POPULATION OF ORIGIN BY USING DENTAL TRAITS AND ANOMALIES: A NEURAL NETWORK APPROACH

To predict the population of origin based on dental traits and anomalies, the population-stratified distribution of dental traits and anomalies was seen [Table 4]. Statistically significant differences were observed for the distribution of shovel-shaped incisor ($P = <0.001$), the cusp of Carabelli ($P = <0.001$), Talon's cusp ($P = <0.001$), mesiodens ($P = 0.01$), DE ($P < 0.001$), peg lateral ($P < 0.001$), macrodontia ($P = <0.001$), AI ($P = 0.03$), and hypodontia/anodontia ($P = <0.001$) among the populations. The prevalence of Talon's cusp was the highest in Jaat (9.5%), with complete absence in Garhwali and Gujjar populations. Shovel-shaped incisors were present in all Garhwali participants (100%) and lowest in the Jaat Population (17.6%). The cusp of Carabelli was highest in Khatri (39%) and lowest in Gujjar (9.9%) population. Macrodontia (2.7%) and AI (2.7%) were only present in the Jaat population, and hypodontia (10.8%) showed the highest prevalence in Jaats. Furthermore, mesiodens (4.4%) occurred the highest in the Gujjar population, and DE (11.8%) and peg lateral incisors (12.9%) were highest in the Khas Bodhi population. No significant difference was observed in the distribution of other dental anomalies among various populations.

Table 3: Prevalence of dental traits and anomalies in the overall study sample

	Nature of dental trait and anomaly	Frequency (%)
Dental Traits	Shovel-shaped incisor	297 (65.4%)
	Cusp of Carabelli	107 (23.6%)
Dental Anomalies	Talon's cusp	9 (2%)
	Dens evaginatus	16 (3.5%)
	Peg Lateral (Microdontia)	18 (4%)
	Macrodontia	2 (0.4%)
	Amelogenesis imperfecta	2 (0.4%)
	Dentinogenesis imperfecta	1 (0.2%)
	Hypodontia/anodontia	18 (4%)
	Mesiodens	5 (1.1%)
	Supernumerary/hyperdontia	8 (1.8%)
	Transposed tooth	3 (0.7%)
	Midline diastema	72 (15.9%)
	Teeth crowding	120 (26.4%)

Neural network modelling was performed to predict the population of origin by using the studied dental parameters. The modelling algorithm assigned normalised importance to dental traits and anomalies for population prediction [Figure 2]. The most important traits and anomalies in population prediction were shovel-shaped incisors, the cusp of Carabelli, and DE, with normalised importance of 100%, 39%, and 33.4%, respectively. The least important parameters were supernumerary tooth, macrodontia, and transposed tooth, with normalised importance of 10.8%, 6.7%, and 6.6%, respectively. As DI was found in only one sample unit and AI was found in only two sample units, the model algorithm removed them from the analysis.

Table 4: Population-wise distribution of dental traits and anomalies among the participants

	Nature of dental trait and anomaly	KB (*N*=85) *n* (%)	JT (*N*=74) n (%)	KH (*N*=105) *n* (%)	GH (*N*=99) *n* (%)	GJ (*N*=91) *n* (%)	*P*
Dental traits	Shovel-shaped incisors	83 (97.6)	13 (17.6)	53 (50.5)	99 (100)	49 (53.8)	<0.001*
	Cusp of Carabelli	13 (15.3)	20 (27)	41 (39)	24 (24.2)	9 (9.9)	<0.001*
Dental anomalies	Talon'scusp	1 (1.2)	7 (9.5)	1 (1)	0 (0)	0 (0)	<0.001*
	Dens evaginatus	10 (11.8)	0 (0)	0 (0)	4 (4)	2 (2.2)	<0.001*
	Peglateral	11 (12.9)	3 (4.1)	0 (0)	2 (2.0)	2 (2.2)	<0.001*
	Macrodontia	0 (0)	2 (2.7)	0 (0)	0 (0)	0 (0)	<0.001*
	Amelogenesis imperfecta	0 (0)	2 (2.7)	0 (0)	0 (0)	0 (0)	0.03*
	Dentinogenesis imperfecta	0 (0)	1 (1.4)	0 (0)	0 (0)	0 (0)	0.27
	Hypodontia/anodontia	5 (5.9)	8 (10.8)	4 (3.8)	1 (1)	0 (0)	<0.001*
	Mesiodens	0 (0)	1 (1.4)	0 (0)	0 (0)	4 (4.4)	0.01*
	Supernumerary/hyperdontia	2 (2.4)	0 (0)	1 (1)	4 (4)	1 (1.1)	0.27
	Transposed tooth	1 (1.2)	1 (1.4)	1 (1)	0 (0)	0 (0)	0.68
	Midline diastema	13 (15.3)	9 (12.2)	15 (14.3)	15 (15.2)	20 (22)	0.46
	Teeth crowding	26 (30.6)	21 (28.4)	24 (22.9)	27 (27.3)	22 (24.2)	0.76

* significant at $P<0.05$; N=Sample size of respective populations; n=number of participants in which respective dental traits and anomalies were found; KB=Khas Bodhi; JT=Jaat; KH=Khatri; GH=Garhwali; GJ=Gujjar

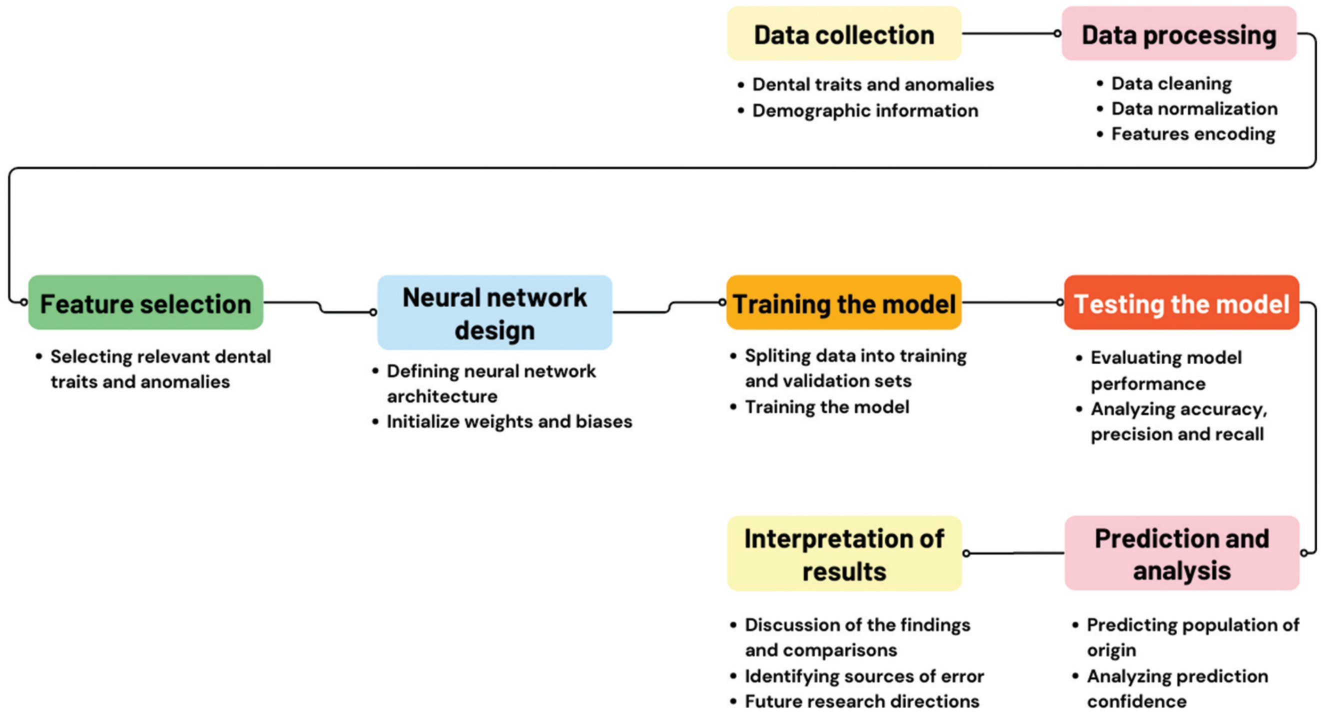

Figure 1: Workflow illustrating steps from data collection to result interpretation in predicting population of origin

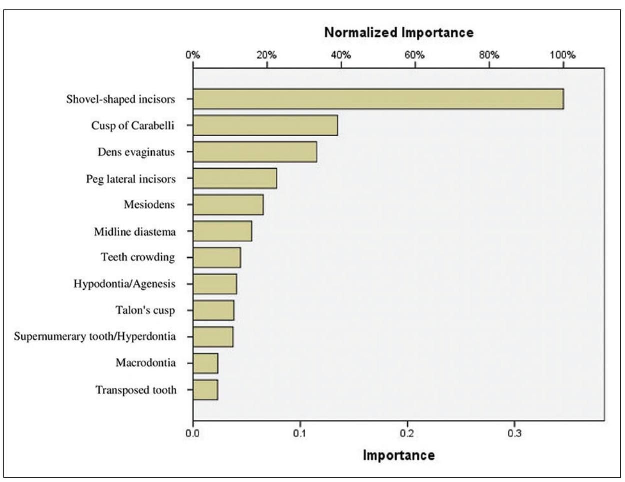

Figure 2: Graph showing the importance of each dental trait and anomaly in population prediction

In the analysis of our training and test set data, we observed intriguing patterns of prediction accuracy across various populations. For the Khas Bodhi population in the training set, we encountered a mix of outcomes. While 28 individuals were accurately predicted as Khas Bodhi, we noticed that 22 were mistakenly identified as Garhwali, and eight were misclassified as Gujjar. The test set continued to present a dynamic challenge, with eight correct predictions alongside 14 instances where Khas Bodhi individuals were incorrectly classified as Garhwali, and five instances as Gujjar. The Jaat population exhibited a challenging scenario. In the training set, only one individual was correctly identified as Jaat, and there were various misclassifications, spanning Khas Bodhi, Khatri, Garhwali, and Gujjar. The test set displayed a similar complexity, with only one correct prediction and several misclassifications, including Khas Bodhi, Khatri, and Gujjar. The Khatri population showed considerable challenges in the training set, with a mix of correct predictions and misclassifications, notably as Khatri, Garhwali, and Gujjar. However, in the test set, there was a marked improvement, as 10 individuals were correctly classified, and the number of misclassifications was notably reduced. The Garhwali population had the highest training set accuracy, with 47 correct predictions and relatively fewer misclassifications. This trend carried over to the test set, with 18 accurate predictions and limited misclassifications. The Gujjar population demonstrated consistent performance, with 36 individuals correctly identified in the training set. However, they also faced misclassifications, including Khas Bodhi, Khatri, Garhwali, and Gujjar. In the test set, 13 individuals were correctly classified, while still contending with some misclassifications.

The modelling results demonstrated varying degrees of accuracy in predicting the five populations under study. Notably, the Garhwali population stood out as the most accurately predicted, achieving a recall percentage of 78.3% in the test set [see Table 5]. The Gujjar population followed with a recall percentage of 43.3%. The Khatri population exhibited a recall percentage of 33.3%, while the Khas Bodhi population yielded a recall of 29.6%. In contrast, the Jaat population had the lowest recall percentage at 7.1%, indicating a relatively less accurate prediction for this specific group.

DISCUSSION

Forensic odontologists work with law enforcement to identify the dental evidence gathered from crime scenes or mass mortality events. To identify deceased victims in a disaster, dental traits and anomalies of the corpse are compared with the antemortem information.[37] To further the forensic odontological investigations in the Indian context, the present study explored the prevalence and patterns of dental traits and anomalies in five North Indian populations and predicted the population of origin based on dental traits and anomalies.

In the study sample, some of the most prevalent dental traits and anomalies were shovel-shaped incisors, teeth crowding, the cusp of Carabelli, midline diastema, peg lateral incisors, and hypodontia. Previous studies from India and other Asian countries have reported similar prevalence rates of shovel-shaped incisors,[38–40] anterior dental crowding,[41] and peg-shaped incisors[42,43] but higher prevalence of the cusp of Carabelli[44] and hypodontia.[45,46] The prevalence of midline diastema in previous studies has been reported to be as low as 1.6% and as high as 64.6%.[47–49] The present study found an overall prevalence of midline diastema at 15.9%.

Shovel-shaped incisors are uncommon or non-existent in Europeans and Africans, but they predominate in Asians, groups descended from Asians, and Native Americans.[50–52] The prevalence of shovel-shaped incisors in the present study was 65.4%, comparable to previous studies, which reported an overall prevalence of 66.1% and 68.2% in the Asian and Indian populations, respectively.[38–40] A study on the South Indian population found an overall prevalence of anterior dental crowding at 27.37%;[41] this concords with our study, which found an overall prevalence of 26.4%.

Carabelli's trait appears to be most prevalent among Europeans for permanent dentition, followed by Africans, with Asians, having the lowest prevalence percentage.[44] According to the current study, the study group's total prevalence was 23.6%, which is lower than the earlier findings.[44,53,54] This disparity may be caused because the selected populations are not involved in the previous studies and due to the study's methodological differences. The lower prevalence of Carabelli's trait in the present study can also be attributed to the fact that some of the study groups share their genetic ancestry with Tibetans and East Asians, which have a lower prevalence of Carabelli's trait.[44]

In permanent dentition, the mean prevalence of peg-shaped teeth is around 1.8% worldwide, although a little higher (3.3%) among the Asian Population.[43] According to Ooshima *et al*.[42] and Fujita *et al*.,[55] the prevalence of peg-shaped teeth in the permanent dentition of the Japanese Population is 3.2% and 0.7%, respectively. However, Fujita *et al*.[55] did not study primary and permanent dentition separately. In the current study, the prevalence of peg-shaped incisors was 4%, comparable to the number published by Ooshima *et al*.[42] and Hua *et al*.[43]

Polder *et al*.[45] and Khalaf *et al*.[46] reported the prevalence of congenitally missing teeth (hypodontia) to be 6.4% on average. The prevalence of hypodontia in the present study was lower, with a frequency of 4%. This difference could be because we examined only permanent dentition in our study participants above 18 years of age, eliminating

Table 5: Neural network modelling for population prediction based on the combination of dental traits and anomalies

Sample	Observed	Predicted						Accuracy Percent	Precision Percent	F-1 Score
		KB (*n*)	JT (*n*)	KH (*n*)	GH (*n*)	GJ (*n*)	Recall Percent			
Training set	KB (*N*=58)	28	0	0	22	8	48.3%	80.4%	45.1%	0.47
	JT (*N*=57)	3	1	22	7	24	1.8%	82.8%	100%	0.03
	KH (*N*=75)	3	0	19	31	22	25.3%	74.9%	42.2%	0.32
	GH (*N*=76)	20	0	0	47	9	61.8%	68.8%	39.1%	0.48
	GJ (*N*=61)	8	0	4	13	36	59.0%	73.0%	36.3%	0.45
	Overall Percent	19.0%	0.3%	13.8%	36.7%	30.3%		Overall Recall Percent: 40.1%		
Test set	KB (*N*=27)	8	0	0	14	5	29.6%	75.0%	40.0%	0.34
	JT (*N*=14)	2	1	9	0	2	7.1%	89.5%	100%	0.13
	KH (*N*=30)	1	0	10	11	8	33.3%	74.1%	45.4%	0.38
	GH (*N*=23)	4	0	0	18	1	78.3%	68.5%	34.6%	0.48
	GJ (*N*=30)	5	0	3	9	13	43.3%	73.3%	44.8%	0.44
	Overall Percent	16.1%	0.8%	17.7%	41.9%	23.4%		Overall Recall Percent: 40.3%		

N=Sample size of respective populations; *n*=number of participants in which respective dental traits and anomalies were found; KB=Khas Bodhi; JT=Jaat; KH=Khatri; GH=Garhwali; GJ=Gujjar any potential for group bias. In addition, our sample size was smaller. According to Rakhshan,[56] prevalence varies depending on the nature of the target sample and is much greater among orthodontic patients (1% higher) than in the general population.

The prevalence of the abovementioned anomalies was followed by DE, Talon's cusp, supernumerary tooth, and mesiodens. The phrase 'Mongoloid or oriental premolar' indicates that DE is mainly seen in Asian populations.[57,58] Depending on ancestry and variations in diagnostic criteria, the incidence of DE ranges from 0.1% to 15%.[57–59] We found an overall prevalence of DE to be 3.5%. Talon's cusp prevalence varies from 0.06 to 7.70%, with Asian and Arabic populations having greater prevalence rates. Decaup *et al*.[60] reported a mean Talon's cusp prevalence of 1.67%; this is almost comparable to the present study, which found an overall prevalence of 2%. Supernumerary teeth are often solitary and can range in prevalence from 1.3% to 3.5%[61] or 0.15% to 3.8%[62] in permanent dentition. In the current study, the prevalence of supernumerary teeth was 1.8%, which concurs with previous studies.[51,62]

Transposed teeth, macrodontia, AI, and DI were the least prevalent dental anomalies in the present study. Tooth transposition prevalence varies between 0.09%% and 1.4%.[63–65] The prevalence of this anomaly in the general population generally stays below 1%.[66–68] The prevalence of transposed teeth was 0.7% in our study. Furthermore, studies have reported the prevalence of macrodontia ranging from 0.2% to 1.9%;[22,42,69–73] this concords with the present study, which found an overall macrodontia prevalence of 0.4%.

The prevalence of AI is 1.25:10,000 in Israel, 43:10,000 in Turkey, 10:10,000 in Argentina, and 14:10,000 in Sweden. These numbers indicate that the average occurrence of AI across the globe is <1 in 200 (or <0.5%).[74] This aligns with the present study, which found an overall prevalence of 0.4%. A study on the Indian population reported the prevalence rate of DI to be 0.09%.[75] We found an overall 0.2% prevalence for DI. This difference can be attributed to the nature and size of the study sample. However, another study reported an overall prevalence of 0.33% for DI,[76] comparable to the present study. In earlier investigations, mesiodens prevalence ranged between 0.1% and 1.9%.[77–80] The overall prevalence of mesiodens among North Indians was reported to be 1.4%,[78] comparable to the present study's overall prevalence of 1.1%.

When we examined the population-wise distribution of dental traits and anomalies, we found significant differences among the studied populations in the prevalence of Talon's cusp, shovel-shaped incisors, the cusp of Carabelli, DE, peg lateral incisors, macrodontia, AI, hypodontia, and mesiodens. In our neural network modelling, shovel-shaped incisors, the cusp of Carabelli, DE, and peg lateral incisors emerged as the top four predictors of population groups due to their significant distribution differences. Notably, the Garhwali and Khas Bodhi populations exhibited the highest prevalence of shovel-shaped and peg lateral incisors, respectively. In addition, DE was also the most prevalent dental anomaly in both of these populations. This observed pattern can be attributed to the genetic affinities between population groups from Himachal Pradesh and Uttarakhand states and Tibetan and East Asian populations,[81,82] These Asian populations are known to have a higher prevalence of shovelling,[50–52] peg lateral incisors,[43] and DE[57,58] compared to other population groups.

Following shovel-shaped incisors, the cusp of Carabelli was identified as the second most important predictor of populations in our study. The Khatri population reported the highest prevalence of the cusp of Carabelli, followed by the Jaats. This higher prevalence in these populations can be linked to Indo-European speakers in Punjab and Haryana, who share genetic affinities with several European populations[83,84] known for their higher prevalence of the cusp of Carabelli.[31]

Our neural network modelling showed that the Garhwali population could be predicted with the highest accuracy among all the studied populations. This was because the top predictor, shovel-shaped incisors, was present in all Garhwali participants. Conversely, the recall percentage was the lowest for the Jaats (7.1%). Notably, Khas Bodhi individuals from Himachal Pradesh were often misinterpreted as Garhwali individuals from Uttarakhand, while Jaats from Haryana were frequently confused with Khatri individuals from Punjab. This prediction error can be attributed to the close genetic relationships between the populations of Himachal and Uttarakhand, as well as the genetic influence of Punjab on Haryana. To enhance the robustness of prediction models, further studies should be undertaken.

Some of the strengths of the present study are that, in contrast to samples of pedodontics and orthodontic patients, the present study is a population-based study, constituting a general population, hence a representative sample. Dental examinations conducted on the general population are likely to have the following advantages: the permanent dentition could be examined because the participants were above 18 years of age; bias, such as that present in samples of only orthodontic patients, is eliminated; samples drawn from different north Indian regions could capture the possible inter-population variations in dental traits and anomalies. Participants who were found to have dental anomalies that needed radiological confirmation for a conclusive diagnosis were required to take an IOPA at the discretion of the examiners. The information gathered was then relayed and utilised for finalising the anomaly. The findings may thus be compared favourably to earlier research that examined dental anomalies from orthopantomogram archives.

The primary limitations of our study were its relatively smaller sample size and the absence of scales or grading in the assessment of dental traits. Instead, we simply reported their presence or absence. This binary approach, while efficient for data collection, may overlook subtle variations or gradations in dental characteristics that could provide deeper insights into the population under investigation. Future research could benefit from incorporating a more nuanced grading system to enhance the precision of dental trait assessments. Furthermore, we acknowledge the complexities surrounding the identification of an individual's ethnicity, a subject that inherently presents challenges and sensitivity. Our research underscores the intricate nature of this endeavour, highlighting the need for caution and a comprehensive approach when dealing with ethnicity identification. In conclusion, our work aims to enhance the forensic process by providing an additional layer of evidence for consideration, recognising the inherent complexities involved in the identification of both individuals and their ethnic backgrounds.

CONCLUSION

The findings of our study indicate that dental traits and anomalies can be valuable for personal identification. Shovel-shaped incisors were the most prevalent dental trait among the participants. Moreover, shovel-shaped incisors were found to be the most important predictor of population, with the accuracy being the highest for the Garhwali population. Our research has yielded an identification recall rate of 78.3%. While we acknowledge that this may seem relatively low, it is essential to emphasise that the proposed method serves as a corroborative tool within the context of individualisation. In forensic science, achieving absolute certainty in identification can be exceptionally challenging, and our approach contributes to the overall body of evidence available for analysis. It is quite likely that constructing an individual's biological profile through the assessment of dental traits and anomalies will prove useful in cases involving unidentified remains, particularly when dealing with mutilated and dismembered body parts, or in situations where the cadaver has undergone advanced stages of putrefaction or charring. Further research involving other Indian populations with a larger sample size can help strengthen the findings reported in the present study.

Ethics approval and consent to participate

Each participant provided informed written and signed consent before the study. The study was conducted in compliance with the Helsinki declaration and after receiving ethical approval from Departmental Ethics Committee, Department of Anthropology, University of Delhi (ethical clearance ref no.: Anth/2021-22/07/002).

Consent for publication

All the participants of the study gave their consent for the publication of identifiable details, which can include photograph(s) and/or videos and/or case history and/or details within the text ("Material") to be published in the above Journal and Article.

Availability of data and material

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Authors' contributions

S.K.: Writing-original draft preparation, Data collection, Methodology, and Software; R.S.: Data collection and Methodology; M.K.KP.: Data collection and Methodology; K.N.S.: Conceptualization of the idea; M.P.S.: Conceptualization of the idea; S.J.: Proofreading and Editing.

Financial support and sponsorship

NA.

Conflicts of interest

There are no conflicts of interest.

REFERENCES

1. James H, Berketa J, Higgins D, Lake A, Cirillo G. Disaster victim management: Role of forensic odontology. Encyclopedia of Forensic and Legal Medicine. Second Edition. Academic Press. 2016. p. 288–304.
2. Krogman WM, Iscan MY. The Human Skeleton in Forensic Medicine. Charles C. Thomas, Springfield, IL; 1986. p. 202–8.
3. Hinchliffe J. Forensic odontology, part 2. Major disasters. Br Dent J 2011;210:269–74.
4. Pretty IA, Sweet D. A look at forensic dentistry – Part 1: The role of teeth in the determination of human identity. Br Dent J 2001;190:359–66.
5. Hinchliffe J. Forensic odontology, Part 1. Dental identification. Br Dent J 2011;210:219–24.
6. Vij K. Textbook of Forensic Medicine and Toxicology: Principles and

Practice. 5th ed. New Delhi: Reed Elsevier India Private Limited-A Division of Elsevier; 2011.
7. Williams LN. An introduction to forensic dentistry. Gen Dent 2013;61:16–7.
8. Tinoco RL, Martins EC, Daruge E Jr, Daruge E, Prado FB, Caria PH. Dental anomalies and their value in human identification: A case report. J Forensic Odontostomatol 2010;28:39–43.
9. Whittaker DK, MacDonald DG. A Colour Atlas of Forensic Dentistry. Wolfe Medical Publications; 1989.
10. Yaacob H, Narnbiar P, Naidu MD. Racial characteristics of human teeth with special emphasis on the Mongoloid dentition. Malay J Pathol 1996;18:1–7.
11. Edgar HJH. Estimation of Ancestry using Dental Morphological Characteristics. J Forensic Sci 2013;58(Suppl 1):S3–8.
12. Nirmala SVSG, Gaddam KR, Vimaladevi P, Nuvvula S. Protostylid: A case series. Contemp Clin Dent 2013;4:352.
13. Townsend G, Bockmann M, Hughes T, Brook A. Genetic, environmental and epigenetic influences on variation in human tooth number, size and shape. Odontology 2012;100:1–9.
14. Tamang R, Singh L, Thangaraj K. Complex genetic origin of Indian populations and its implications. J Biosci 2012;37:911–9.
15. Bhasin MK, Sharma A, Singh IP. A study on dental traits among Jats of Haryana, North India. Indian J Phys Anthropol Hum Genet 1979;5:7–18.
16. Dasgupta SN, Kulkarni SS, Kulkarni V. Dental variations among Jains and Marathas of Maharashtra. Man India 1992;72:385–403.
17. Sharma JC, Kaul V. Dental morphology. J Indian Anthropol Soc 1977;12:213–26.
18. Bejou D, Wray B, Ingram TN. Determinants of relationship quality: An artificial neural network analysis. J Bus Res 1996;36:137–43.
19. Amiri M, Derakhshandeh K, Amiri M, Derakhshandeh K. Applied artificial neural networks: From associative memories to biomedical applications. In: Suzuki K, editor. Artificial Neural Networks - Methodological Advances and Biomedical Applications. IntechOpen; 2011. Available from: https://www.intechopen.com/state.item.id. [Last accessed on 2022 Oct 26].
20. Thong Z, Tan JYY, Loo ES, Phua YW, Chan XLS, Syn CKC. Artificial neural network, predictor variables and sensitivity threshold for DNA methylation-based age prediction using blood samples. Sci Rep 2021;11:1744.
21. Xu C, Qu H, Wang G, Xie B, Shi Y, Yang Y, *et al.* A novel strategy for forensic age prediction by DNA methylation and support vector regression model. Sci Rep 2015;5:17788.
22. Patil S, Doni B, Kaswan S, Rahman F. Prevalence of dental anomalies in Indian population. J Clin Exp Dent 2013;5:e183.
23. Hattab FN, Yassin OM, Al-Nimri KS. Talon cusp in permanent dentition associated with other dental anomalies: Review of literature and reports of seven cases. J Dent Child 1996;63:368–76.
24. Scott GR, Irish JD. Human tooth crown and root morphology: The Arizona state university dental anthropology system. Human Tooth Crown and Root Morphology. Cambridge University Press; 2017. Available from: https://www.cambridge.org/core/books/human-tooth-crown-and-root-morphology/002B1295FC31F98209FC97C86F39F926. [Last accessed on 2023 Jan 24].
25. Chetty M, Beshtawi K, Roomaney I, Kabbashi S. MACRODONTIA: A brief overview and a case report of KBG syndrome. Radiol Case Rep 2021;16:1305–10.
26. Hagiwara Y, Uehara T, Narita T, Tsutsumi H, Nakabayashi S, Araki M. Prevalence and distribution of anomalies of permanent dentition in 9584 Japanese high school students. Odontology 2016;104:380–9.
27. Crawford PJM, Aldred M, Bloch-Zupan A. Amelogenesis imperfecta. Orphanet J Rare Dis 2007;2:1–11.
28. Shields ED, Bixler D, El-Kafrawy AM. A proposed classification for heritable human dentine defects with a description of a new entity. Arch Oral Biol 1973;18:543-53.
29. Al-Ani A, Antoun J, Thomson W, Merriman T, Farella M. Hypodontia: An update on its etiology, classification, and clinical management. Biomed Res Int 2017;2017:9378325.
30. van Buggenhout G, Bailleul-Forestier I. Mesiodens. Eur J Med Genet 2008;51:178–81.
31. Rajab LD, Hamdan MAM. Supernumerary teeth: Review of the literature and a survey of 152 cases. Int J Paediatr Dent 2002;12:244–54.
32. Matsumoto MAN, Stuani MBS. Tooth transposition: A multidisciplinary approach. Dental Press J Orthod 2018;23:97–107.
33. Das P, Dkhar W, Pradhan A. An evaluation of dental crowding in relation to the mesiodistal crown widths and arch dimensions in southern Indian population. J Clin Diagn Res 2017;11:TC10.
34. Lavelle CLB. The distribution of diastemas in different human population samples. Eur J Oral Sci 1970;78:530–4.
35. Stecker S, DiAngelis AJ. Dens evaginatus: A diagnostic and treatment challenge. J Am Dent Assoc 2002;133:190–3.
36. Mishra P, Dasar P, Sandesh N, Kumar S, Chand BR, Airen B, *et al.* Dental camp experience in Lifeline Express (LLE) train among rural population of central, India. J Clin Diagn Res 2014;8:ZC72.
37. Pittayapat P, Jacobs R, de Valck E, Vandermeulen D, Willems G. Forensic odontology in the disaster victim identification process. J Forensic Odontostomatol 2012;30:1.
38. King N, Tsai J, Wong H. Morphological and numerical characteristics of the southern Chinese dentitions. Part II: Traits in the permanent dentition. Open Anthropol J 2010;3:71–84.
39. Kirthiga M, Manju M, Praveen R, Umesh W. Ethnic Association of Cusp of Carabelli trait and shoveling trait in an Indian population. J Clin Diagn Res 2016;10:ZC78.
40. Ling JYK, Wong RWK. Incisal morphology of southern Chinese. Open Anthropol J 2008;1:19–25.
41. Shivakumar KM, Chandu GN, Subba Reddy VV, Shafiulla MD. Prevalence of malocclusion and orthodontic treatment needs among middle and high school children of Davangere city, India by using Dental Aesthetic Index. J Indian Soc Pedod Prev Dent 2009;27:211.
42. Ooshima T, Ishida R, Mishima K, Sobue S. The prevalence of developmental anomalies of teeth and their association with tooth size in the primary and permanent dentitions of 1650 Japanese children. Int J Paediatr Dent 1996;6:87–94.
43. Hua F, He H, Ngan P, Bouzid W. Prevalence of peg-shaped maxillary permanent lateral incisors: A meta-analysis. Am J Orthod Dentofacial Orthop 2013;144:97–109.
44. Smitha T, Venkatesh D, Veeresh M, Hema K, Sheethal H, Vidya M. The cusp of Carabelli: Frequency, distribution and type in the Bengaluru population. J Oral Maxillofac Pathol 2018;22:418.
45. Polder BJ, Van't Hof MA, van der Linden FPGM, Kuijpers-Jagtman AM. A meta-analysis of the prevalence of dental agenesis of permanent teeth. Community Dent Oral Epidemiol 2004;32:217–26.
46. Khalaf K, Miskelly J, Voge E, Macfarlane TV. Prevalence of hypodontia and associated factors: A systematic review and meta-analysis. Sage 2014;41:299–316.
47. Nainar S. Incidence and etiology of midline diastema in a population in South India (Madras). Angle Orthod 1989;59:277–82.
48. Onyeaso CO. Prevalence of malocclusion among adolescents in Ibadan, Nigeria. Am J Orthod Dentofacial Orthop 2004;126:604–7.
49. Liu JF, Hsu CL, Chen HL. Prevalence of developmental maxillary midline diastema in Taiwanese children. J Dent Sci 2013;8:21–6.
50. Turner CG. Major features of Sundadonty and Sinodonty, including suggestions about East Asian microevolution, population history, and late Pleistocene relationships with Australian Aboriginals. Am J Phys Anthropol 1990;82:295–317.
51. Kimura R, Yamaguchi T, Takeda M, Kondo O, Toma T, Haneji K, *et al.* A common variation in EDAR is a genetic determinant of shovel-shaped incisors. Am J Hum Genet 2009;85:528–35.
52. Neville B, Damm D, Allen C, Chi A. Oral and Maxillofacial Pathology. Elsevier Health Sciences; 2015.

53. Saravanan R. Prevalence of cusp of Carabelli in Madurai population. Int J Recent Sci Res 2020;11:38805–7.
54. AL Shethri S. The prevalence of the Carabelli cusp in selected Saudi population. King Saud Univ J Dent Sci 2011;2:13–6.
55. Fujita Y, Hidaka A, Nishida I, Morikawa K, Hashiguchi D, Maki K. Developmental anomalies of permanent lateral incisors in young patients. J Clin Pediatr Dent 2009;33:211–6.
56. Rakhshan V. Meta-analysis and systematic review of factors biasing the observed prevalence of congenitally missing teeth in permanent dentition excluding third molars. Prog Orthod 2013;14:1–12.
57. Rawlani SM, Rawlani SS, Bhowate RR, Chandak RM, Khubchandani M. Racial characteristics of human teeth. Int J Forensic Odontol 2017;2:38.
58. Kocsis GS, Marcsik A, Kókai EL, Kocsis KS. Supernumerary occlusal cusps on permanent human teeth. Acta Biol Szeged 2002;46:71–82.
59. Lin C, Llacer-Martinez M, Sheth C, Jovani-Sancho M, Biedma B. Prevalence of premolars with dens evaginatus in a Taiwanese and Spanish population and related complications of the fracture of its tubercle. Eur Endod J 2018;3:118.
60. Decaup PH, Garot E, Rouas P. Prevalence of talon cusp: Systematic literature review, meta-analysis and new scoring system. Arch Oral Biol 2021;125:105112.
61. Ata-Ali F, Ata-Ali J, Peñarrocha-Oltra D, Peñarrocha-Diago M. Prevalence, etiology, diagnosis, treatment and complications of supernumerary teeth. J Clin Exp Dent 2014;6:e414.
62. Hattab FN. Double talon cusps on supernumerary tooth fused to maxillary central incisor: Review of literature and report of case. J Clin Exp Dent 2014;6:e400–7.
63. Hatzoudi M, Papadopoulos M. Prevalence of tooth transposition in Greek population. Hel Ortho Rev 2006;9:11–22.
64. Onyeaso C, Onyeaso A. Occlusal/dental anomalies found in a random sample of Nigerian schoolchildren. Oral Health Prev Dent 2006;4:181–6.
65. Celikoglu M, Miloglu O, Oztek O. Investigation of tooth transposition in a non-syndromic Turkish anatolian population: Characteristic features and associated dental anomalies. Med Oral Patol Oral Cir Bucal 2010;15:716–36.
66. Ruprecht A. The incidence of transposition of teeth in dental patients. J Pedod 1985;9:244–9.
67. Sandham A, Harvie H. Ectopic eruption of the maxillary canine resulting in transposition with adjacent teeth. Tandlaegebladet 1985;89:9–11.
68. Burnett S. Prevalence of maxillary canine—first premolar transposition in a composite African sample | The Angle Orthodontist. Angle Orthod 1999;69:187–9.
69. Vani NV, Saleh SM, Tubaigy FM, Idris AM. Prevalence of developmental dental anomalies among adult population of Jazan, Saudi Arabia. Saudi J Dent Res 2016;7:29–33.
70. Kazanci F, Celikoglu M, Miloglu O, Ceylan I, Kamak H. Frequency and distribution of developmental anomalies in the permanent teeth of a Turkish orthodontic patient population. J Dent Sci 2011;6:82–9.
71. Yassin SM. Prevalence and distribution of selected dental anomalies among Saudi children in Abha, Saudi Arabia. J Clin Exp Dent 2016;8:e485.
72. Basalamah M, Baroudi K. Prevalence of oro-dental anomalies among schoolchildren in Sana'a city, Yemen. EMHJ-East Mediterr Health J 2016;22:34–9.
73. Fekonja A. Prevalence of dental developmental anomalies of permanent teeth in children and their influence on esthetics. J Esthet Restor Dentistry 2017;29:276–83.
74. Gadhia K, McDonald S, Arkutu N, Malik K. Amelogenesis imperfecta: An introduction. Br Dent J 2012;212:377–9.
75. Gupta SK, Saxena P, Jain S, Jain D. Prevalence and distribution of selected developmental dental anomalies in an Indian population. J Oral Sci 2011;53:231–8.
76. Mohan S, Viswanath B, Thakur J, Tekriwal S, Singh A, Jaiswal R. Prevalence and distribution of selected dental anomalies in the patients reporting to dental institute, RIMS, Ranchi. J Pharm Bioallied Sci 2021;13(Suppl 2):s993.
77. Mukhopadhyay S. Mesiodens: A clinical and radiographic study in children. J Indian Soc Pedod Prev Dent 2011;29:34.
78. Patil S, Pachori Y, Kaswan S, Khandelwal S, Likhyani L, Maheshwari S. Frequency of mesiodens in the pediatric population in North India: A radiographic study. J Clin Exp Dent 2013;5:e223.
79. Kazanci F, Celikoglu M, Miloglu O, Yildirim H, Ceylan I. The frequency and characteristics of mesiodens in a Turkish patient population. Eur J Dent 2011;5:361–5.
80. Colak H, Uzgur R, Tan E, Hamidi M, Turkal M, Colak T. Investigation of prevalence and characteristics of mesiodens in a non-syndromic 11256 dental outpatients. Eur Rev Med Pharmacol Sci 2013;17:2684–9.
81. Lu D, Lou H, Yuan K, Wang X, Wang Y, Zhang C, *et al.* Ancestral origins and genetic history of Tibetan highlanders. Am J Hum Genet 2016;99:580–94.
82. Liu CC, Witonsky D, Gosling A, Lee JH, Ringbauer H, Hagan R, *et al.* Ancient genomes from the Himalayas illuminate the genetic history of Tibetans and their Tibeto-Burman speaking neighbors. Nat Commun 2022;13:1203.
83. Bamshad M, Kivisild T, Watkins WS, Dixon ME, Ricker CE, Rao BB, *et al.* Genetic evidence on the origins of Indian caste populations. Genome Res 2001;11:994–1004.
84. Mahal DG, Matsoukas IG. Y-STR haplogroup diversity in the Jat population reveals several different ancient origins. Front Genet 2017;8:121.