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TECHNICAL NOTE

ODONTOLOGY

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Analysis of Enamel Rod End Patterns on Tooth Surface for Personal Identification—Ameloglyphics

ABSTRACT: Ameloglyphics is the study of enamel rod end patterns on a tooth surface. Our aim was to study the *in vivo* analysis of enamel rod end patterns on tooth surfaces for personal identification. In this study, the maxillary left canine and 1st premolar of 30 men and 30 women were included. The cellulose acetate peel technique was used to record enamel rod endings on tooth surfaces. Photomicrographs of the acetate peel imprint were subjected to VeriFinger Standard SDK v5.0 software for obtaining enamel rod end patterns. All 120 enamel rod end patterns were subjected to visual analysis and biometric analysis. Biometric analysis revealed that the enamel rod end pattern is unique for each tooth in an individual. It shows both intra- and interindividual variation. Enamel rod end patterns were unique between the male and female subjects. Visual analysis showed that wavy branched subpattern was the predominant subpattern observed among examined teeth. Hence, ameloglyphics is a reliable technique for personal identification.

KEYWORDS: forensic science, ameloglyphics, enamel rod end patterns, visual analysis, biometric analysis, personal identification

In forensic science, fingerprints, dental patterns, and more recently, DNA analyses are used for personal identification, but these identification methods may not be efficient when bodies are decomposed, burned, or in cases where only small fragments of calcified tissues are available for identification. In such situations, dental hard tissues gain importance for identification based on the condition of the deceased. Teeth can withstand extreme temperatures and are resistant to postmortem decomposition. Moreover, restorative materials used by dentists for restoring teeth are also resistant to postmortem destruction to a certain extent. Therefore, the use of dental evidence is the method of choice in establishing an identity from badly burned, traumatized, decomposed, and skeletonized remains (1,2).

Odontogenesis is genetically modulated. The formation of enamel is a highly organized dynamic process, in which the ameloblasts lay down enamel rods in an undulating and intertwining path (3). This is reflected on the outer surface of the enamel as a series of enamel rod end patterns. The term "Ameloglyphics" means "the study of enamel rod end patterns" (amelo-enamel, glyphics-carvings) (4).

The aim of this study is to record the enamel rod end patterns on human tooth surfaces and check their uniqueness for personal identification.

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Materials and Methods

Sample

This study was conducted in the Department of Oral and Maxillofacial Pathology, Meenakshi Ammal Dental College and Hospital, Chennai. A total of 30 men and 30 women within the age group of 17–24 years were selected randomly. The maxillary left canine and the 1st premolar of each individual were included for this study. The study protocol was explained to all the individuals, and informed consent was obtained from them to participate actively in this study.

Inclusion criteria:

- Male or female
- Age: 17–24 years
- Canine and 1st premolar of the maxillary left quadrant
- Clinically normal teeth

Exclusion criteria:

- Grossly decayed teeth
- Hypoplastic teeth
- Fractured teeth
- Abraded/eroded teeth
- Restored teeth

Procedure

Scaling and polishing were carried out for all the individuals participating in the study. The 0.5×0.5 cm^2 area on the facial surface (middle third) of the teeth was conditioned using 10% orthophosphoric acid for 20 sec, washed with water, and then dried. A thin layer of acetone was applied over a small piece of cellulose acetate film and placed immediately over the conditioned surface of the teeth without any finger pressure for 15 min (Fig. 1). Acetone dissolves a layer of cellulose acetate, and the dissolute settles down along the irregularities on the enamel surface. The film was gently peeled after 15 min and observed under a light microscope (Olympus CH20; Zenith Engineers, Agra, India). Photomicrographs of the imprints were obtained at 40× magnification using a digital camera in 1.4× digital zoom (Nikon 5200; Nikon Inc., Melville, NY). The photomicrograph was then cropped at the center to 2000 × 1500 pixels dimension using a MICROSOFT PICTURE MANAGER software (Microsoft Corp., Redmond, WA) (Fig. 2).

The photomicrograph was subjected to biometric analysis using VeriFinger Standard SDK v5.0 software (Neurotechnologija Software Systems, Vilnius, Lithuania) (Fig. 3), which recognizes the patterns of enamel rod endings as a series of lines running in varying directions and memorizes them in the database with a specific identification number and minutiae points on it (Fig. 4). Enamel rod end patterns developed by the software can be stored in the computer for record purposes in the form of black and white lines (without minutiae points), which can be used for visual analysis.

FIG. 1—*Cellulose acetate film placed on tooth surface for recording enamel rod endings.*

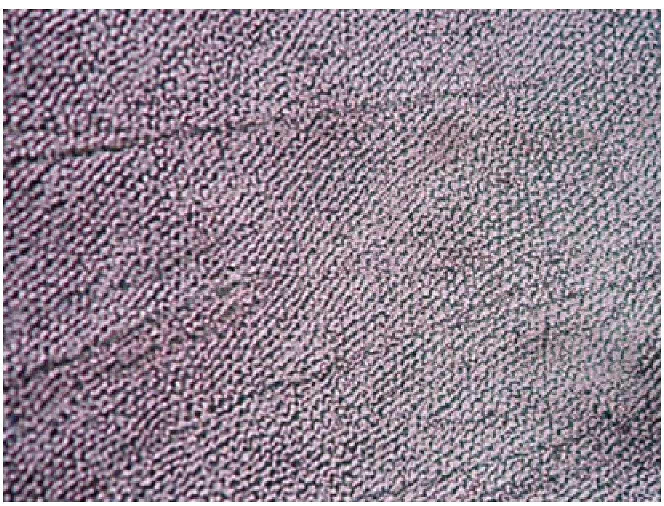

FIG. 2—*Photomicrograph of enamel rod endings recorded from the tooth surface, 40×.*

Results

Each enamel rod end pattern is composed of a series of lines that represent series of adjacent enamel rod ends. These lines were seen running in varying directions creating distinct subpatterns.

Visual Analysis

Group analysis of enamel rod end patterns of the male and female subjects:

Visual analysis of 120 enamel rod end patterns (both the canine and 1st premolar) of 30 men and 30 women yielded eight distinct subpatterns. They were categorized as linear branched, linear unbranched, wavy branched, wavy unbranched, whorl open, whorl closed, loop, and stem. Each enamel rod end pattern had a combination of few subpatterns but was predominated by a single subpattern.

The wavy branched subpattern was the most predominant pattern seen among 120 enamel rod end patterns. It was observed in 97% of the examined teeth in the study. Whorl closed was the least common subpattern, occurring only in 3% of the teeth (Table 1).

Analysis of enamel rod end patterns of the canine and 1st premolar in the male subjects:

Visual analysis of 60 enamel rod end patterns of (the canine and 1st premolar) 30 men yielded eight distinct subpatterns. Each pattern had a combination of all the eight subpatterns.

The wavy branched subpattern was the predominant pattern seen among 60 enamel rod end patterns. It was observed in 96% of the examined teeth in the study. The whorl closed subpattern was not seen in any of the examined teeth (Table 2).

Analysis of enamel rod end patterns of the canine and 1st premolar in the female subjects:

Visual analysis of 60 enamel rod end patterns of (the canine and 1st premolar) 30 women yielded eight distinct subpatterns. Each pattern had a combination of all the eight subpatterns.

The wavy branched subpattern was the predominant pattern seen among 60 enamel rod end patterns. It was observed in 98% of the examined teeth in the study. Whorl closed was the least common subpattern, occurring only in 6% of the teeth (Table 3).

Biometric Analysis

- Each enamel rod end pattern was composed of a series of lines representing a series of adjacent enamel rod ends and minutiae points.
- Enamel rod end patterns were unique for each tooth in an individual.
- Enamel rod end patterns showed both intra- and interindividual variation (Fig. 5).
- Enamel rod end patterns were unique between the male and female subjects.

Discussion

The groups of ameloblasts run in a wavy course toward the surface as they secrete enamel matrix, which results in the tortuous course of the enamel rods for dentino-enamel junction to the enamel surface. These enamel rods end on the tooth surface at

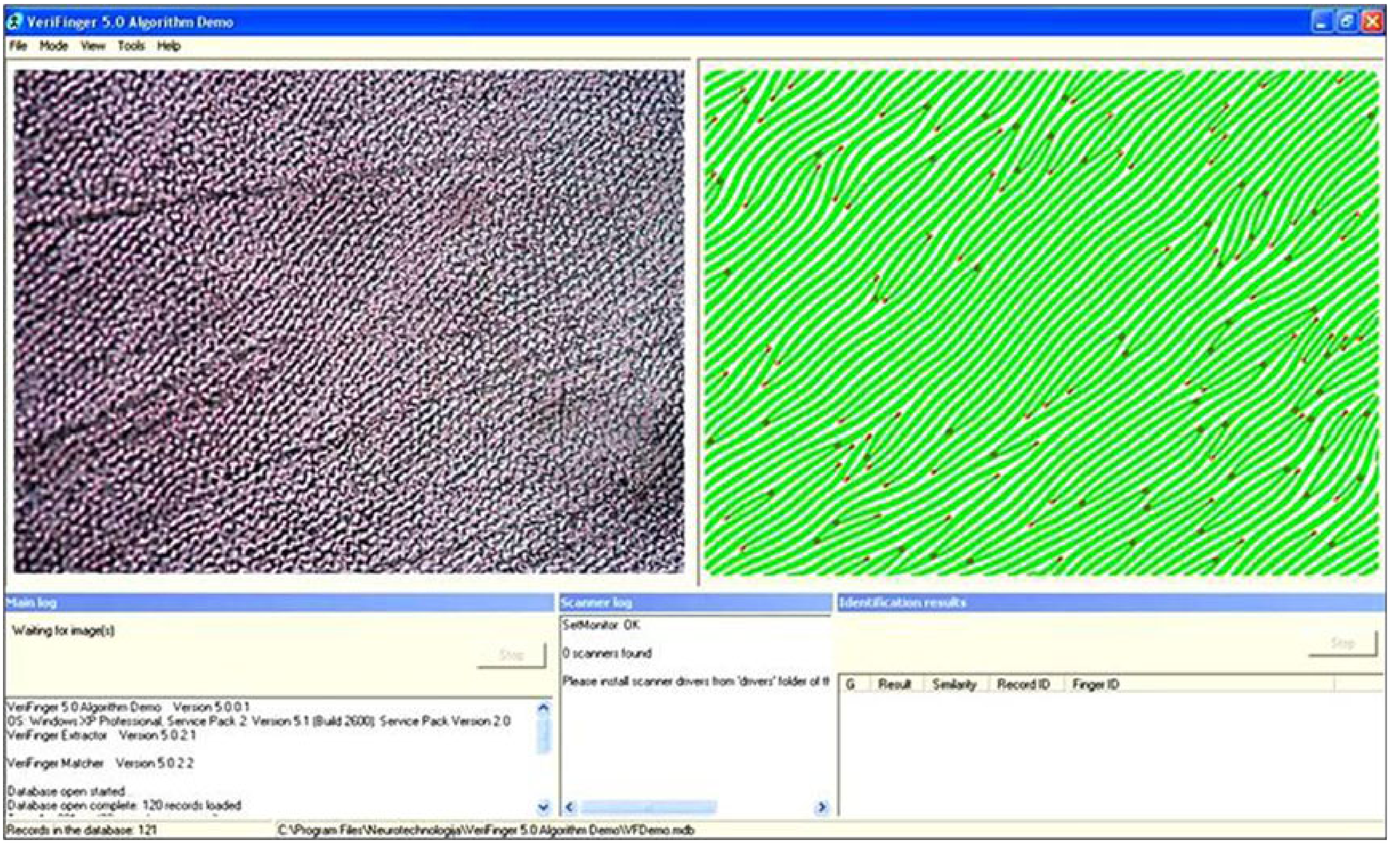

FIG. 3—*Enrolling photomicrograph and extraction of enamel rod end patterns in VeriFinger SDK v5.0*

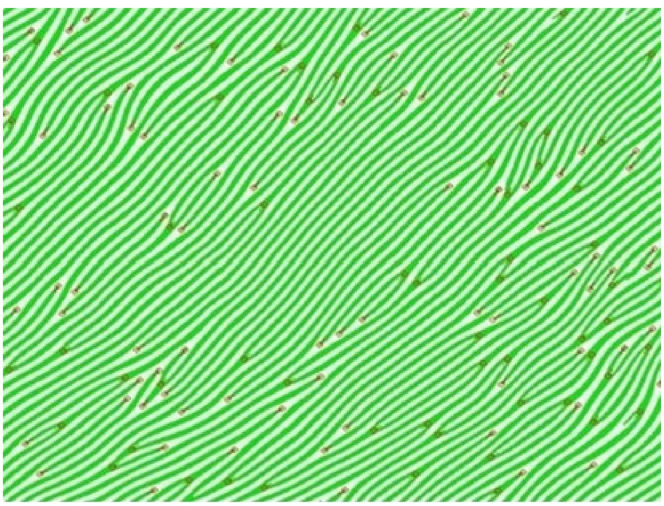

FIG. 4—*Enamel rod ends pattern with minutiae points.*

TABLE 1—*Enamel rod end subpatterns in both male and female subjects.*

Subpattern	Total No. of Teeth	No. of Teeth Showing Following Subpattern	Percentage
Linear branched	120	102	85
Linear unbranched	120	88	73
Wavy branched	120	116	97
Wavy unbranched	120	83	69
Whorl open	120	7	6
Whorl closed	120	4	3
Loop	120	48	40
Stem	120	13	11

TABLE 2—*Enamel rod end subpatterns in both the canine and 1st premolar in the male subjects.*

Subpattern	Total No. of Teeth	No. of Teeth Showing Following Subpattern	Percentage
Linear branched	60	53	88
Linear unbranched	60	41	68
Wavy branched	60	58	96
Wavy unbranched	60	37	61
Whorl open	60	5	8
Whorl closed	60	0	0
Loop	60	21	35
Stem	60	4	6

TABLE 3—*Enamel rod end subpatterns in both the canine and 1st premolar in the female subjects.*

Subpattern	Total No. of Teeth	No. of Teeth Showing Following Subpattern	Percentage
Linear branched	60	49	81
Linear unbranched	60	47	78
Wavy branched	60	59	98
Wavy unbranched	60	46	76
Whorl open	60	3	5
Whorl closed	60	4	6
Loop	60	28	46
Stem	60	9	15

different levels and in different directions, resulting in specific patterns on the tooth surface. The study of these enamel rod end patterns is known as ameloglyphics (4,5).

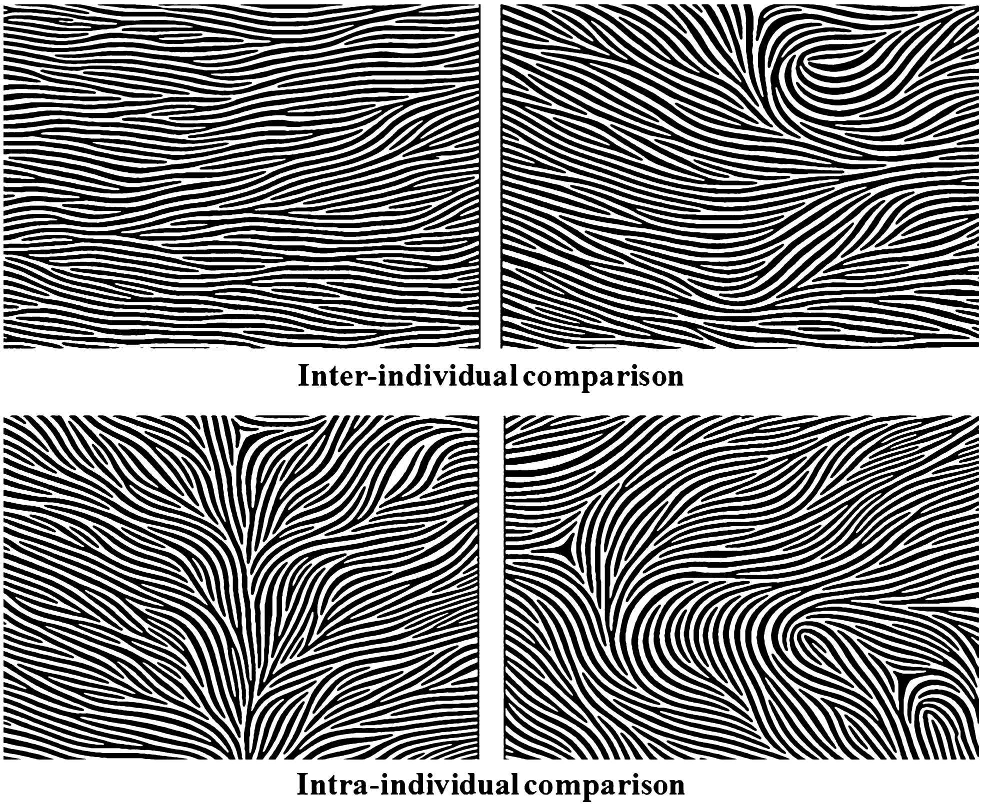

FIG. 5—*Inter-and intraindividual comparison of enamel rod end patterns. (Top) Patterns of the canines from different individuals (interindividual comparison) and (bottom) patterns of canine and 1st premolar from same individual (intraindividual comparison).*

In anthropology and petrology, numerous peel techniques like the plastic peel technique (McCrone (1963), Stewart and Taylor (1965), and Frank (1965)), flexible peel technique (McCrone (1963)), and rigid peel method (Frank, 1965) are used to study surface details of the rocks (6). Scott et al. (7) used metal-shadowed collodion replicas to study tooth surfaces by means of optical microscopy. They observed enamel rod ends, perikymata, scratches, cracks, and various developmental defects and concluded that structural details visualized in these replicas were inaccurate.

Fusun et al. (6) used the acetate peel technique to study dental structures, especially enamel, without routine decalcification, sawing, and mounting processes. They concluded that the technique is a simple, inexpensive, accurate, and rapid method for studying surface details. So, this technique was selected for our study to record enamel rod endings from tooth surfaces for biometric analysis.

In our study, 10% phosphoric acid was used to condition the tooth surface before recording the enamel rod endings using cellulose acetate film. Commonly, 10% phosphoric acid is used as a cavity conditioner to remove the smear layer and increase the bonding strength of restorative materials (8). Carstensen et al. reported that 10% phosphoric acid is the lowest concentration at which all the etching patterns were observed with minimal risk of enamel decalcification (8,9).

Ramenzoni et al. (10) were the first to use the fingerprint identification and verification software (VeriFinger Demo 4.2, SDK⁄Fingersec) and could satisfactorily evaluate the uniqueness of Hunter-Schreger bands for personal identification. This prompted us to choose VeriFinger SDK v5.0 software for the analysis of enamel rod end patterns for personal identification in this study.

Manjunath et al. (4) analyzed enamel rod end patterns on 30 extracted teeth and concluded that these patterns were unique for each tooth, and it can be used for personal identification. They coined the term "*Ameloglyphics*" similar to the term "*Dermatoglyphis*" (study of fingerprints). They classified the subpatterns into eight groups for visual analysis, like linear branched, linear unbranched, wavy branched, wavy unbranched, whorl open, whorl closed, loop, and stem.

In our study, enamel rod end patterns were unique for each tooth in an individual and showed both intra- and interindividual variation, irrespective of the sex. Observations of our *in vivo* study indicate the uniqueness of enamel rod end pattern and its utility for personal identification. Gupta et al. (11) analyzed enamel rod end patterns on 60 extracted tooth specimens. They concluded that these patterns exhibit both intra- and interindividual similarity and were unique for each tooth in an individual, which was consistent with our results in the present study.

Minutiae points are the identification points marked and stored by the VeriFinger SDK v5.0 software for identification, verification, and comparison of patterns. Minutiae points are discontinuities of the lines seen as line endings, dots, very small lines, ponds, bifurcations, and loops. Manjunath et al. (12) conducted an *in vitro* study to check the reliability of automated biometrics (VeriFinger Standard SDK v5.0) in the analysis of enamel rod end patterns. In their study, enamel rod endings were recorded three times from the same specific area on 10 extracted teeth (the mid-labial surface) using the acetate peel technique. The acetate peels were subjected to biometric analysis with VeriFinger Standard SDK v5.0 software to obtain the enamel rod end patterns. The respective minutiae point scores and their positions on each enamel rod end pattern were recorded and analyzed using the software. They observed that the VeriFinger SDK v5.0 software was able to identify subsequent records of the same area of the same tooth with the original record stored in the database of the software. Comparison of the minutiae scores using Cronbach's test also showed that there was no significant difference in the minutiae scores obtained (>0.6). Hence, VeriFinger Standard SDK v5.0 software was a reliable biometric tool in the analysis of enamel rod end patterns for personal identification.

The results of our study authentically showed that enamel rod end pattern is unique for each tooth in an individual and may be used as an adjunct to other methods for personal identification. This is a simple, inexpensive, and rapid method, which can be performed by even a dental auxiliary staff member. Usually, this method of personal identification can be recommended for those individuals working in dangerous occupations such as fire fighters, soldiers, jet pilots, divers, frequent air travelers, and people who live or travel to politically unstable areas, prior to their assignments. However, we recorded enamel rod end patterns only of the canine and 1st premolar of the maxillary left quadrant in this study, but for practical application of this robust technique in mass disasters, terrorist attacks, wars, etc., we recommend recording of all the teeth. In addition, development of a fiber-optic laser scanner that can scan the complete tooth surface can make this technique practically applicable in various fields.

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