RESEARCH PAPER

Forensic Identification using Dental Anatomy through Palatal Rugoscopy

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Received: 25th May, 2026; **Revised:** 6th June, 2026; **Accepted:** 8th June, 2026; **Available Online:** 17th June, 2026

ABSTRACT
Forensic dentistry plays a vital role in the identification of individuals in many legal applications, particularly in the case of a mass tragedy, homicide or an unidentified body. Palatal rugae have been emerging as a unique identification feature in the fast-growing area of forensic odontology. This review study aims to analyze the morphology, anatomic and forensic importance of the palatal rugae with special focus on the use as a reliable tool for personal identification. Forensic Odontology plays a crucial role in human identification when other methods such as fingerprints and DNA are not applicable. The palatal rugae (ridges on the anterior hard palate) have been of interest as a unique and reliable forensic identification mark. They are very stable, trauma-resistant, and possess individual individuality, which makes them very useful tools in investigations of trauma. In this review paper, the limitations, forensic applications, categorisation systems and palatal rugae anatomy as a means of identification are discussed. The study further illustrates the importance of rugae patterns in today's forensic science practice by assessing advances in digital and Artificial Intelligence (AI) technologies that analyze the rugae pattern. Forensic Identification is a crucial part of both criminal and civil investigations; it also comprises Dental Records. Palatal rugoscopy (palatal rugae patterns) is unique and adaptable to environmental changes, making it a valuable forensic odontology tool. This review paper discusses the significance of palatal rugoscopy, categorisation schemes, the method and possible applications in forensic identification. This study presents the advantages and disadvantages of this approach, and provides some suggestions for future research by reviewing several research publications.
Keywords: Forensic Dentistry, Forensic Odontology, Rugoscopy, Palatal Rugae, Dental Records.
How to cite this article: Sharma D, Yadav A, Kumar R. Forensic Identification using Dental Anatomy through Palatal Rugoscopy. Int J Drug Deliv Technol. 2026;16(61s): 434-438. DOI: 10.25258/ijddt.16.61s.47
Source of support: Nil.
Conflict of interest: None.

Introduction:
Forensic dentistry, which assists in the identification of individuals through bite markings, dental morphology and dental records, is an essential branch of forensic science. One of these, the palatal rugae, is of particular interest due to their peculiar patterns, resistance to physical and chemical damage, and because they have not undergone any postmortem changes. This paper, based on the existing literature, tries to provide a comprehensive evaluation of palatal rugae in terms of their morphology, classification and forensic significance. Forensic science is the combination of several fields to identify people. Forensic odontology is one of them, which identifies identity based on dental structures. There are palatal rugae (transverse ridges) on the front of the hard palate that offer reliable and distinguishing identification. This paper discusses the palatal rugae and their significance in human identity from an anatomical, developmental and forensic perspective. Forensic Dentistry is the special focus of dentistry used to assist in legal investigations. It is well known that dental records can be used to identify individuals, but the need for more distinctive identifiers has led to the investigation of palatal rugae. The ridges on the anterior part of the hard palate are called palatal rugae. These unique patterns can be used for individual identification as they can be affected by developmental, environmental and hereditary influences. Because of their distinctive features, palatal rugae—transverse ridges on the anterior portion of the hard palate—have attracted a lot of interest in forensic dentistry. These landmarks are also stable and unique, like fingerprints, and are anatomical. This paper aims to explore the role of palatal rugae as an identifier in forensic dentistry, with emphasis on their role, analysis techniques and consequences for human identification.

Historical Context:

The use of palatal rugae for forensic purposes was first suggested in the late 19th century, a practice known as rugoscopy, or palatoscopy. Since then, it has been demonstrated by several studies that palatal rugae patterns remain stable in an individual's life and can be used reliably as a form of identification, particularly in cases where more reliable methods of identification, like fingerprints, are not possible due to decomposition or trauma.

Morphological and Anatomical Characteristics of Palatal Rugae:

Meaning and Categorisation - The set of ridges or folds on the front part of the hard palate is known as the palatal rugae. They are classified by size, shape and arrangement. The following are the main shapes:

- **Linear -** Long and straight;
- **Curvilinear -** wavy and curved;
- **Circular -** looped and rounded.

Unless surgically or orthodontically modified, palatal rugae are produced during the 12th and 14th week of intrauterine life and do not change over the course of a person's lifetime. These rugae can be categorised using several criteria, such as:

The length - Measurements of individual rugae may vary widely.

Number: People have 5-10 pairs of rugae.

Orientation: Genetic variables will affect the layout, which could vary from person to person.

Growth and Variability - Palatal rugae begin to develop in utero and continue to vary throughout childhood. Rugae morphology is influenced by several variables such as age, sex and ethnicity. Studies revealed that rugae patterns vary significantly between populations and hence are a useful parameter for forensic or anthropological studies (Kumar et al., 2018; Kaur et al., 2020). The intrauterine phase is the time when palatal rugae develop, and they are relatively stable throughout life. Formed by the proliferation of the connective tissue and epithelium of the palatal mucosa.

Genetic Factors - Scientific studies have shown that hereditary factors play a significant role in the production of palatal rugae. The twin studies revealed that the concordance of rugae patterns among monozygotic twins was higher than the concordance for dizygotic twins, suggesting a genetic relationship (Kumar et al., 2019).

Classification System of Palatal Rugae:

There are several schemes of palatal rugae classification based on length, shape and direction:

- **Thomas and Kotze (1983)** grouped items under the headings circular, wavy, curved and straight.
- **The Lysell Classification (1955)** classified rugae based on length into three categories: primary, secondary, and tertiary.
- **Da Silva et al. (2008)** focused on patterns of interruption, branching, and unification.
- **Martínez-Sahuquillo et al.** Categorisation (integrates earlier systems) focuses on the standardisation of forensic investigations is facilitated by each classification.

Studies have shown that the palatal rugae are very reliable forensic indicators, as they are unlikely to change after death and are resistant to trauma, decomposition and fire. Declares the reality of palatal rugae, and displays originality throughout life and beyond.

Methodologies for Rugoscopy in Forensic Identification:

- **Conventional Techniques / Manual methods (Visual examination, intraoral photography, casts)** - Palatal rugae analysis has been traditionally based on visual evaluations and physical measurements. Some of the methods used for documenting rugae patterns are calliper measurements and/or photographic documentation (Kumar et al., 2017). Also referred to as visual examination, this involves comparing and direct observation of rugae patterns.
- **Due to technological advances, analysis of digital data has been developed (3D scanning, software-assisted analysis, artificial intelligence integration)** - Digital techniques for palatal rugae analysis have been created. More accurate measurements and comparisons are made possible by methods like software-based analysis and image processing. Digital tools can be used to store and retrieve data and increase the accuracy of identification of rugae (Kaur et al., 2021).
- **Analysis of Statistics (Matching patterns in forensic databases) -** Assessing the distinctiveness and dependability of palatal rugae patterns requires the use of statistical techniques. The importance of rugae patterns in forensic identification has been evaluated using a variety of statistical tests, such as discriminant function analysis and chi-square testing (Singh et al., 2020).
- **Techniques for superimposition -** It includes tracing rugae patterns on acetate paper and overlaying them on casts or photos of suspected people. Forensic specialists use comparative study of ante-mortem and post-mortem rugae patterns to help with identification cases.

Forensic Applications of Palatal Rugoscopy:

- **Individual Identification -** Like fingerprints, palatal rugae patterns are specific to each individual. Research indicates that they are highly accurate in differentiating between people.

- **Recognising People in Large-Scale Disasters -** It has been suggested that palatal rugae are a useful tool for identifying victims of large-scale catastrophes like natural disasters or terrorist acts. They can be compared to dental records because of their distinctive patterns and resistance to post-mortem changes (Kumar et al., 2020). In the event of a mass disaster, palatal rugae provide a robust and convenient substitute for conventional identification methods.
- **Among the major applications of palatal rugae in forensic research is identification in burned or decomposed bodies.** Even if there is extensive damage, such as in the case of burns or other trauma, palatal rugae patterns have been shown to remain unchanged. For example, in one case study, the patterns of rugae from old dentures matched up well to pinpoint a badly burned body.
- **The palatal rugae can not only be used for identification but also as an estimate of age at death.** Research has proved that the number as well as the shape of rugae changes with age, and this can be used to age a body at death (Kaur et al., 2019).
- **Ethnicity and Gender Studies –** The studies have revealed that there is a difference in palatal rugae patterns between ethnic groups and gender. The trait can be helpful for identification of unidentified remains based on rugae pattern which are unique for a community (Singh et al., 2021). The findings of the research have shown that there are insignificant differences in the morphology of rugae between males and females and that some rugae are more prevalent within specific ethnic groups.
- **The analysis of palatal rugae is particularly useful** in cases where other methods (e.g. fingerprinting) are not practicable. In edentulous individuals (those who are without teeth), the palatal rugae will provide a unique identifier for identification by comparison with dental records.
- **Distinctiveness of Rugae Designs -** One important consideration in the use of palatal rugae patterns for forensic identification is their uniqueness. According to studies, there is very little chance that two people will have the same rugae patterns, which supports their usage as a trustworthy identifying marker (Kumar et al., 2018). Hence, it is more reliable, authentic and valid.

Recent Advances and Technological Integration:

- **Analyses Based on Software and Digital Imaging -** In forensic comparisons, digital scanning and 3D imaging methods improve precision and repeatability. 3D imaging and digital archiving aid better pattern comparison. Forensic databases are utilized for population-based research and integrate with other forensic modalities (DNA profiling, dental records, and facial recognition) for better identification.
- **Applications of Machine Learning and Artificial Intelligence -** AI-driven rugae pattern detection for automated forensic identification has been investigated in recent publications.

Limitations and Challenges of Palatal Rugoscopy:

- **Adaptability Because of Dental Treatments -** The natural rugae pattern can be changed by orthodontic operations, extractions, and other dental interventions. Differences are brought about by orthodontic procedures.
- **Accuracy Issues -** Research suggests that depending only on palatal rugae may result in identification accuracy rates that are lower (around 79%) because of the possibility of obliteration during denture construction.
- **Degradation of postmortem tissue in harsh environments** - In extreme heat or at high temperatures, the tissues of the palatal rugae usually degrade and as a result of which it becomes quite difficult to identify the victim. Recommendations & Future Directions:
- **Requirement for standardisation in analysis techniques –** A standard technique or methodology has not yet been developed to analyze the palatal rugae.

Future Directions and Recommendations:

Future studies should focus on establishing a standard classification; developing digital and AI analysis of the rugae; conducting large population studies for validation; and interdisciplinary research with forensic anthropology and genetics.

Conclusion:

The resilience and distinctiveness of palatal rugae are ideal characteristic for use in forensic identification. As research progresses, standardised protocols for examining these anatomical features need to be developed to increase the reliability of these features as forensic markers. In order to increase identification accuracy, future research should concentrate on resolving the difficulties presented by dental procedures and creating increasingly complex imaging methods. Palatal rugae are an authentic identifying factor in forensic odontology. They are unique, difficult to alter and

have technological applications- features that make them particularly interesting forensically. Their suitability for use in forensic investigations will be further improved by ongoing research and developments in digital and AI-based analysis. Palatal rugoscopy is a unique and consistent pattern, making it a good technique for forensic identification. Although there are some limitations, this approach is getting more consistent thanks to technological advances. Its applicability in human identification will be improved by further research and combination with contemporary forensic techniques.

Summary:

This review paper is about the use of palatal rugae, the ridges on the front of the hard palate, as a reliable technique for forensic identification, particularly when there are no other viable options, such as fingerprinting or DNA analysis. The palatal rugae have advantages as they are stable, trauma-resistant, and unique to each individual. The paper reviews the morphology, the anatomy and the classification of rugae in the palate (in terms of shape, length, number and orientation), while also highlighting the role of genetics in palatal rugae development and variability. Different rugoscopes and methods of rugoscopy, such as conventional, digital, statistical and superimposition, are discussed. Emphasis is placed on the forensic use of palatal rugoscopy, including individual identification, mass disaster victim identification and identification in burned and decomposed bodies, as well as other means of identification. The latest developments in software-based and digital image analyses are also discussed, as well as the integration of machine learning and artificial intelligence. The paper recognizes the limitations and challenges of palatal rugoscopy, such as changes resulting from dental procedures and the necessity of uniformity in analysis procedures and further research that can make it more useful and reliable for the use of the forensic science.

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