

January - June 2026

Volume 35

Issue 1

PRINT ISSN: 2277-1867

ONLINE ISSN: 2277-8853



JOURNAL OF FORENSIC MEDICINE SCIENCE AND LAW

Official Publication of Medicolegal Association of Maharashtra

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**MULTISPECIALITY, MULTIDISCIPLINARY, NATIONAL
PEER REVIEWED, OPEN ACCESS, MLAM (SOCIETY) JOURNAL
Indexed with Scopus (Elsevier)**

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JOURNAL OF FORENSIC MEDICINE SCIENCE AND LAW

(Official Publication of Medicolegal Association of Maharashtra)

Email.id: mlameditor@gmail.com

PRINT ISSN:

2277-1867

ONLINE ISSN:

2277-8853

Original Research Article

Accuracy Evaluation of 3D Palatal Rugae for Personal Identification in Monozygotic Twins: A Pilot Study

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Article Info

Received on: 27.12.2025

Accepted on: 22.03.2026

Key words

Palatal Rugae,
3D Scanning,
Study Model,
Monozygotic Twins,
Forensic Odontology.

Abstract

Background: Rugoscopy serves as a vital alternative for personal identification when primary methods like fingerprints or DNA are unavailable. While 3D scanning offers digital advantages, its application for palatal rugae analysis in Indonesia remains limited. **Objective:** To evaluate the concordance between traditional study models and 3D scanning technology in identifying palatal rugae patterns among monozygotic twins. **Methods:** This cross-sectional analytic observational pilot study specifically focused on 10 pairs of monozygotic twins ($n = 20$). Palatal rugae were recorded using both physical study models and 3D scanning, then classified based on Thomas and Kotze's criteria (number, length, shape, and unification). Data were analyzed using paired t-tests for mean differences and Pearson's correlation to determine the strength of association between the two methods. **Results:** Descriptive analysis showed a consistent distribution of the dominant wavy pattern and divergent unification across both methods. Statistical analysis revealed no significant differences between study model and 3D scanning measurements for wavy ($p=0.100$) and divergent types ($p=0.083$). Furthermore, a strong positive correlation was observed between the two methods for both wavy ($r=0.888$, $p<0.001$) and divergent types ($r=1.000$, $p<0.001$). **Conclusion:** The 3D scanning method demonstrates high agreement with traditional study models, confirming its feasibility as a reliable digital tool for forensic identification. Despite being monozygotic twins, distinct variations in palatal rugae patterns were still identifiable, supporting the uniqueness of rugoscopy.

1. Introduction

Forensic identification is a critical component of medicolegal investigations, particularly in cases involving mass disasters, criminal acts, or decomposed remains. While DNA analysis, fingerprinting, and dental records are the primary methods of identification, their application

can be limited when bodies are severely burned, decomposed, or when antemortem records are unavailable.^{1,2,3} In such scenarios, alternative biometric markers that are resistant to post-mortem changes become essential for establishing identity.^{4,5}

How to cite this article: Kristanto R, Oktavia I, Susilahati NL, Susanti DN. Accuracy Evaluation of 3D Palatal Rugae for Personal Identification in Monozygotic Twins: A Pilot Study. J Forensic Med Sci Law. 2026;35(1):33-38. doi: [10.59988/jfmsl.vol.35issue1.7](https://doi.org/10.59988/jfmsl.vol.35issue1.7)

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Rugoscopy, the study of palatal rugae, has emerged as a reliable alternative in forensic odontology. Palatal rugae are unique, stable, and protected by their anatomical position, making them highly resistant to high temperatures, chemical trauma, and decomposition.^{4,5,6} These patterns are so distinct that they remain individualistic even among monozygotic twins, despite their identical genotypes and phenotypes.^{8,9,10} While factors such as orthodontic treatment or thumb-sucking habits can influence minor changes, the core characteristics of the rugae remain a robust tool for personal identification.^{1,11}

Conventionally, rugoscopy is performed using plaster study models. However, these physical models have significant limitations, including their fragility, the risk of degradation over time, and the need for extensive physical storage space.^{12, 13} The transition to digital 3D scanning technology offers a transformative solution. 3D scanning allows for the conversion of physical impressions into high-resolution digital files that are easily stored, retrieved, and analysed.^{14,15} Recent studies, such as those by Simon et al. (2020) and Yilmaz et al. (2019), have demonstrated that 3D digital models provide the necessary efficiency and accuracy to distinguish individuals, including monozygotic twins, for forensic purposes.¹⁶⁻²¹

Despite these global technological advancements, forensic practice in Indonesia still predominantly relies on conventional study models.^{5, 22} There is a significant research gap regarding the accuracy and implementation of 3D digital rugoscopy within the Indonesian forensic context. Given the high demand for efficient and accurate identification methods in the region, evaluating digital alternatives is imperative.

This pilot study aims to evaluate the concordance of palatal rugae measurements between conventional study models and 3D scanning technology. By utilizing monozygotic twins—who represent the highest degree of phenotypic similarity—this research seeks to determine the accuracy and feasibility of 3D scanning as a digital approach for personal identification in forensic dentistry.^{10, 16}

2. Materials and Methods

Study Design and Ethical Approval

This analytic observational study employed a cross-sectional design to evaluate the concordance between conventional study models and digital 3D

scanning. The study protocol was approved by the Ethics Committee of the Faculty of Medicine, Udayana University (No: 0002/UN14.2.2.VII.14/LT/2024). As this research serves as a pilot study to assess the feasibility of digital rugoscopy in a specific population, a sample size of 10 pairs of monozygotic twins ($n = 20$) was recruited. Quota sampling was utilized to ensure the inclusion of rare monozygotic twin pairs who met the stringent inclusion criteria within the study period.^{16,10}

Participant Selection

Participants were selected based on the following inclusion criteria: monozygotic twins aged 16–50 years with healthy oral conditions. Exclusion criteria included history of palatal clefts, active oral lesions (trauma, viral infections, or symptoms of sexually transmitted diseases), current orthodontic treatment, use of removable dentures, or recent tooth extractions that could alter the palatal architecture. Informed consent was obtained from all participants after a thorough explanation of the procedure.

Data Collection and Model Preparation

Clinical history and intraoral examinations were performed to ensure suitability. Maxillary impressions were taken using high-quality alginate (Hygident) and immediately poured with Type III dental stone (Formula Saint-Gobain Pro Dental) to minimize dimensional distortion.¹² To ensure stability during the digital acquisition, a standardized base was prepared for each stone model. Each model was coded with initials to maintain anonymity and stored in protective packaging to prevent physical damage.

3D Scanning and Digital Acquisition

The physical study models were converted into digital format using a high-precision laboratory 3D scanner (3Shape). The resulting digital files were exported in Standard Tessellation Language (.stl) format. All digital measurements and visualizations were performed using the 3Shape ScanIt Dental software (version 2.1.9.1).

Palatal Rugae Analysis and Measurement Units

Palatal rugae patterns were identified and classified according to the criteria established by Thomas and Kotze (**Figure 1**). The evaluation included:

- Rugae Number:** The total count of identifiable rugae on both sides of the palate.
- Rugae Length:** Categorized into primary (>5 mm), secondary (3–5 mm), and fragmentary (2–3 mm).

For statistical analysis, the cumulative length of each category was recorded in millimeters (mm).

3. **Shape and Unification:** Classified as curved, wavy, straight, or circular, and unification as convergent or divergent.

Measurement Reliability and Calibration

To minimize measurement bias and ensure high diagnostic accuracy, all procedures on both physical models (**Figure 2**) and 3D scans (**Figure 3**) were conducted by a single examiner who underwent a rigorous three-stage calibration process, with the entire measurement and classification process overseen and validated by two senior forensic odontology supervisors to ensure strict adherence to Thomas and Kotze's criteria. Intra-observer reliability was subsequently assessed by re-measuring 20% of the total samples after a two-week interval, where the calculated Intraclass Correlation Coefficient (ICC) exceeded 0.90, indicating excellent consistency and reliability of the measurements.

Statistical Analysis

Data were analyzed using SPSS software (version 26). Descriptive statistics were used to characterize the rugae patterns. The Shapiro–Wilk test confirmed the normal distribution of the data. To compare the mean values between the study models and 3D scans, a paired t-test was applied. The strength of the relationship between the two methods was evaluated using Pearson's correlation. Statistical significance was set at $p < 0.05$. For results where $p > 0.05$, it was interpreted as no statistically significant difference between the two methods, indicating high concordance.

3. Results

Characteristics of Palatal Rugae Patterns

The distribution of palatal rugae patterns among the 10 pairs of monozygotic twins was identified using both conventional study models and 3D digital scans. Descriptive analysis (**Table 1**) revealed that primary rugae (>5 mm) were the most prevalent across all samples. The wavy shape was the dominant pattern identified in both methods (Mean: Model = 9.18 mm; Scan = 8.93 mm), followed by the curved and straight types. Regarding unification, the divergent type was the most frequent pattern observed (Mean: Model = 13.41 mm; Scan = 13.56 mm). The low standard deviation values across both platforms suggest high data homogeneity, indicating that 3D scanning captures rugae morphology with a level of consistency comparable to traditional gypsum models.

Figure 1: Forms of Palatal Rugae According to the Thomas and Kotze Classification.

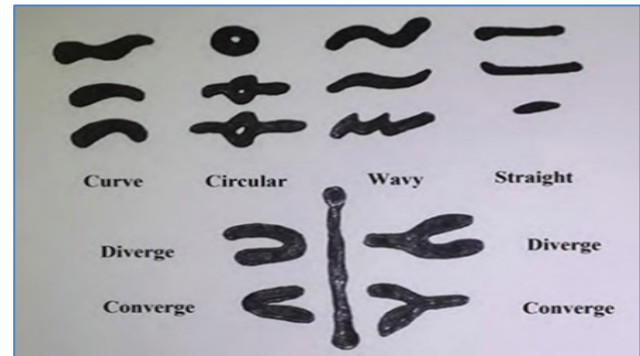


Figure 2: Study Model.

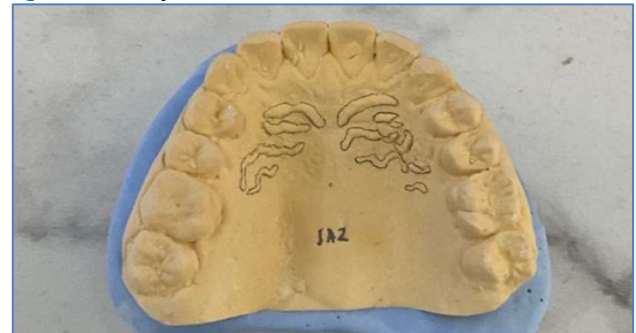
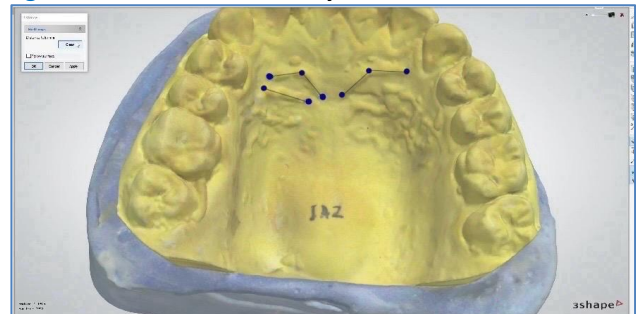


Figure 3: 3D Scan of the Study Model.



Methodological Concordance and Statistical Analysis

Data normality was confirmed via the Shapiro–Wilk test ($p > 0.05$), as detailed in **Table 2**, allowing for parametric comparative testing. To evaluate the agreement between the two measurement methods, a paired t-test was performed on the dominant patterns (Wavy and Divergent). The analysis revealed no statistically significant differences between the study models and 3D scans for the wavy type ($p = 0.100$, $p > 0.05$; that Wavy Model – Wavy 3D Scan) or the divergent type ($p = 0.083$, $p > 0.05$; Divergent Model – Divergent 3D Scan). These findings indicate that the digital 3D scanning method does not significantly deviate from the conventional gold standard in measuring rugae dimensions.

Correlation Analysis

The relationship between physical and digital measurements was assessed using Pearson's

correlation (**Table 3**). A strong and significant positive correlation was observed for the wavy pattern ($r=0.888$, $p<0.001$). For the divergent unification type, the analysis yielded a correlation coefficient of $r=1.000$ ($p<0.001$). While a perfect correlation is rare in biological studies, this result in our sample ($n=6$ for divergent type) reflects the high precision of the 3D software in replicating the linear unification patterns found on the physical models.

Table 1: Descriptive Statistics of Palatal Rugae Measurements in Study Models and 3D Scans

Rugae Type	N	95% CI		Mean	Std. Deviation
		Min.	Max.		
Wavy model	20	5.79	11.80	9.1845	1.30294
Wavy scan	20	5.47	11.80	8.9385	1.37081
Curved model	18	4.40	10.30	7.4522	1.66012
Curved scan	18	5.02	11.00	7.6367	1.71465
Circular model	5	7.84	15.37	10.1500	3.10924
Circular scan	5	8.63	15.69	10.4020	3.03535
Straight model	18	2.55	10.01	5.4033	2.00519
Straight scan	18	2.19	9.92	5.3428	2.04887
Divergent model	6	7.40	27.25	13.4133	7.18293
Divergent scan	6	7.53	27.43	13.5650	7.18433
Konvergent model	2	7.50	9.80	8.6500	1.62635
Konvergent scan	2	7.70	10.00	8.8500	1.62635

Table 2: Shapiro–Wilk Normality Test Results of Dominant Palatal Rugae Types in Study Models and 3D Scans

	Statistic	df	p-value
Wavy model	.958	20	.511 ^a
Wavy scan	.942	20	.267 ^a
Divergent model	.796	6	.054 ^a
Divergent scan	.796	6	.054 ^a

Note: a: normal distribution.

Table 3: Pearson Correlation Test Results of Palatal Rugae in Study Models and 3D Scans

		p-value	Correlation Coefficient
Wavy	Study Model	0.000 ^a	0.888
	3D Scan		
Divergent	Study Model	0.000 ^a	1.000
	3D Scan		

Note: a: significant correlation.

4. Discussion

The high concordance observed between conventional study models and 3D scanning in this pilot study underscores the reliability of digital rugoscopy as a robust forensic tool. The absence of statistically significant differences ($p>0.05$) between the two methods for both wavy and divergent patterns suggests that digital acquisition effectively preserves the morphological integrity of palatal rugae, making it a viable alternative to traditional physical casts. The uniqueness of palatal rugae, even among monozygotic twins, is rooted in complex embryological development. Although monozygotic

twins share identical genotypes, the formation of palatal rugae between the 12th and 14th weeks of intrauterine life is influenced by localized epigenetic factors and the dynamic environment of the fetal oral cavity. Factors such as the mechanical pressure from the developing tongue, the growth rate of the palate, and subsequent environmental influences—including thumb-sucking habits, orthodontic forces, or localized trauma—contribute to the distinct phenotypic expression of rugae patterns.^{1,3,11}

This biological individuality explains why the twins in this study exhibited distinguishable rugae variations despite their genetic identity, reinforcing rugoscopy's status as a "fingerprint" of the hard palate. The finding that palatal rugae can distinguish between monozygotic twins is consistent with the theory of epigenetic variation during prenatal development. While monozygotic twins share an identical genetic blueprint, the morphological development of the palate is a stochastic process influenced by the "micro-environment" of the amniotic sac. According to recent studies^{10,11}, even if the genetic signalling for palatal shelf elevation is identical, the physical space, tongue position, and localized pressure within the uterine environment differ for each twin. This results in subtle but permanent variations in the length, shape, and unification of the rugae.^{10,11}

Furthermore, the stability of these patterns post-birth adds to their forensic value. Unlike other physical traits that may converge in identical twins due to similar lifestyles, palatal rugae are protected by the buccal fat pads and the tongue, remaining unchanged by age or minor systemic physiological shifts. This study confirms that 3D scanning technology is sensitive enough to capture these minute "epigenetic signatures" that distinguish one twin from another, which is often impossible through DNA analysis alone in forensic settings.^{15,16} These anatomical nuances justify the use of rugoscopy as a definitive secondary identifier in specialized odontological cases.

Transitioning from physical study models to 3D scanning offers transformative advantages in forensic odontology. Traditional gypsum models are inherently fragile, prone to dimensional changes over time, and require significant physical storage space.^{12,13} In contrast, 3D scanning produces immutable .stl files that can be stored in cloud-based databases, encrypted for security, and transmitted instantly for global forensic consultation. In the Indonesian

context, where geographical barriers can delay the transport of physical evidence, a digital rugoscopy workflow could significantly expedite victim identification in mass disaster or criminal investigations, particularly when primary identifiers like fingerprints or DNA are compromised.^{4, 5} Our findings align with international studies that validate the precision of digital dental technology. The strong correlation ($r=0.888$ to 1.000) observed in this study mirrors the results of Yilmaz et al.¹⁷ and Taneva et al.,¹⁰ who found no significant differences between digital and manual measurements of dental arches and rugae. The "perfect" correlation ($r=1.000$) found in the divergent unification type, while statistically rare in larger biological datasets, likely reflects the high precision of the 3Shape software in replicating linear landmarks within our specific sample size ($n=6$). Furthermore, our results support the conclusions of Simon et al., who successfully distinguished monozygotic twins using intraoral scanners, highlighting that 3D technology captures minute morphological nuances that are essential for forensic differentiation.¹⁶ Despite the high accuracy reported, the implementation of digital rugoscopy in forensic practice faces hurdles.¹⁸⁻²⁰ The initial accuracy of the digital file remains heavily dependent on the quality of the primary impression.²¹⁻²³ While alginate is a cost-effective material with satisfactory accuracy, any procedural error during the impression-taking or gypsum-pouring stage will be duplicated in the 3D scan.²⁴ Additionally, the high cost of laboratory and intraoral scanners remains a primary barrier to widespread adoption in developing forensic facilities. There are other modalities for human identification such as brain fingerprinting.²⁵

Future research on palatal rugae in monozygotic twins is expected to involve a larger sample size to provide greater variation, thus offering a more comprehensive overview and enhancing the validity of the findings. Furthermore, future studies should use both study models and intraoral 3D scanning applied directly in the patient's oral cavity to advance and expand upon the present research.

Contributor ship of Author: All authors equally contributed. **Ethical Clearance:** Yes

Conflict of interest: None to declare.

Source of funding: None to declare.

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