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## Association between Direction Patterns of Palatal Rugae and Thumbprints: Implications for Forensic Identification

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### Association between Direction Patterns of Palatal Rugae and Thumbprints: Implications for Forensic Identification

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#### **ORIGINAL ARTICLE**

#### Association between Direction Patterns of Palatal Rugae and Thumbprints: Implications for Forensic Identification

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#### ABSTRACT

Palatal rugae have been proven to be useful as a means of individual identification. As there are no antemortem data about palatal rugae, they have to be connected with other indicators, such as fingerprints with available antemortem data. **Objectives**: To assess the association of the direction patterns of palatal rugae prints and thumbprints in the Deutero-Malay sub-race to improve forensic identification. **Methods**: Palatal rugae intraoral photos and thumbprints scans were from 193 Deutero-Malay individuals aged between 18–25 years (170 female, 23 male). ImageJ and Adobe software was used to identify direction patterns of the palatal rugae and thumbprints. **Results**: An antero-posterior direction was the most common direction pattern among right (64.17%) and left (49.26%) palatal rugae and right (58.12%) and left (56.02%) thumbprints. An association with small effect size was found between first right palatal rugae and right thumbprint (p-value = 0.024; Cramer's V = 0.181) and with medium effect size between second left palatal rugae and left thumbprint (p-value = 0.000; Cramer's V = 0.332). **Conclusion**: There is a significant association between the direction patterns of palatal rugae and thumbprints. This finding may lead to the development of a new effective technique in forensic odontology identification.

Key words: Fingerprint, forensic odontology, image processing, palatal rugae

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#### **INTRODUCTION**

Palatal rugae are a series of irregular and asymmetrical ridges located on the anterior third of the palatal mucosa. They extend laterally from the incisive papilla and the anterior part of the palatal raphe.<sup>1,2</sup> Palatal rugae have been proven to be useful in forensic dentistry as an individual identification tool.<sup>3,4</sup> Differences in shape, size, and direction of palatal rugae can be used as special characteristics that can distinguish one individual from another.<sup>1,2,5–7</sup> These characteristics also have a significant differentiation between identical twins.<sup>8</sup> Palatal rugae can be used as a parameter in forensic identification as they are difficult to falsify,

resistant to trauma by protection of surrounding anatomical structures, resistant to decomposition for up to seven days after death, resistant to high-temperature combustion, and distinguishable in different races.<sup>5,7,9-13</sup> One of the disadvantages of using palatal rugae as an individual identification tool is the lack of availability of antemortem data <sup>3,14</sup>. Therefore, for identification purposes, palatal rugae needs to be connected with other individual identification tools such as fingerprints that have easily accessible antemortem data with a high level of authentication.<sup>15</sup>

Palatal rugae develop from a pattern on the epidermal layer that forms after the fusion of the prosessus palatinus in the twelfth to fourteenth weeks of

intrauterine development. Fingerprint patterns develops from the epidermal layer that forms at the volar tip in the tenth to sixteenth weeks of intrauterine development.<sup>9,16</sup> The direction of the pattern growth in the palatal rugae starts from the median palate to the lateral palate; whereas, fingerprint pattern growth starts from the tip and the middle part of the volar pads to the edge of the volar pads.<sup>9,16,19</sup> The formation of those patterns is regulated by a series of gene interactions.<sup>17,18</sup> Previous research showed similarities in the genes involved in the formation of palatal rugae and fingerprint patterns, including the Shh, Wnt, and BMP4 genes.<sup>17,36,37</sup> The interaction of these three genes with several other genes formed a distinctive pattern in fingerprints and palatal rugae through a series of cell proliferation and apoptosis processes.<sup>17,18</sup>Although palatal rugae and fingerprints have similarities in the process of pattern formation, no studies have been able to find a relationship between the two patterns.

As one of the main tools for forensic identification. fingerprints also have several disadvantages. Fingerprint data can be easily damaged if exposed to high temperatures and severe trauma, and they also can easily be lost during the decomposition process.<sup>20</sup> Therefore, it would be valuable for fingerprints to be associated with palatal rugae patterns. Wichnieski et al. <sup>21</sup> studied the association between palatal rugae and thumbprints and classified palatal rugae direction patterns according to Carrea's classification<sup>22</sup>. Meanwhile, thumbprints were classified according to shape pattern, based on Vucetich's classification<sup>16</sup>. Wichnieski et al.<sup>21</sup> did not show a statistically significant association. Unfortunately, there were no other studies with the same method found in the current medical literature to support or compare to these findings. Improvement and adjustment of classification methods are needed to be able to find a relationship between palatal rugae and thumbprints.

The aim of this study was to find an association between palatal rugae and thumbprints using the same method, by classifying patterns according to the direction. Palatal rugae were classified according to Carrea's classification, and thumbprints were classified by adapting the Carrea's classification.

#### **METHODS**

The initial sample consisted of 200 students of the Faculty of Dentistry, Universitas Padjadjaran, Bandung-Indonesia. Participants were of the Deutero-Malay sub-race, and all were aged between 18 and 25 years. Individuals with a history of injury or surgery in the anterior third of the palate and individuals with injury on the thumb that could cause difficulty in reading fingerprints were excluded from the study. The final sample consisted of 193 individuals, 170 females and 23



**Figure 1. a.** Custom-made equipment with an installed intraoral mirror **b.** Optimal angles for upper occlusal photos (45°).



**Figure 2.** Facial midline and mid sutura palatal of the participant must be parallel to the midline of the intraoral mirror while photographing intraoral palatal rugae.

males. The final number of participants was sufficient according to the minimum sample size calculation ( $\alpha = 0.05\%$  and 1- $\beta = 90\%$ ). All examined participants received previous information about the study and signed an informed consent. The study was approved by the Health Research Ethics Committee, Faculty of Medicine, Universitas Padjadjaran, Bandung-Indonesia.

Intraoral photos of palatal rugae of all participants were taken using a digital single lens reflex camera, and thumbprints scans were taken using a fingerprint scanner. Custom-made equipment with an installed intraoral mirror was used to standardize the shooting angle of all intraoral photos (Figure 1.a). This equipment allowed intraoral palatal rugae images with optimal angles for upper occlusal photos (45°) in all participants (Figure 1.b). The American Board of Forensic Odontology scale was affixed to intraoral mirror for calibration to determine actual palatal rugae size from the photo. In the process of photographing palatal rugae prints, facial midline and mid sutura palatal of the participant must be parallel to the midline of the intraoral mirror (Figure 2). The results of all intraoral photos were rotated 180 degrees so that the right side of the photo could simulate the right side of the observer and vice versa.



Figure 3. Results of palatal rugae selection with Adobe® Photoshop® CS8 software



**Figure 4.** Adaptation of Carrea's classification used for thumbprints (red lines show the direction pattern of palatal rugae and thumbprints, blue circles show the position of core and delta in thumbprint)

The fingerprint scanner used in this research was Fingerplus® type FM 200, which could scan fingerprint patterns and produce an image in JPEG format using Zsoft<sup>™</sup> Attendance software. Intraoral photos were processed with Adobe® Photoshop® CS8 image processing software to identify rugae boundaries and open source ImageJ version 1.52a software to analyze the direction of rugae. The Adobe® Photoshop® CS8 software used a magnetic lasso feature to manually identify palatine rugae borders (Figure 3). Intraoral photo size calibration was done by using the set scale feature in the ImageJ software to avoid photo distortion caused by using two different image processing software programs.

The classification method used in this study was Carrea's classification according to direction patterns. In 1955, Carrea developed a classification system to divide palatal rugae into four groups: anteroposterior (AP), postero-anterior (PA), perpendicular (P), and random directions (R).<sup>22</sup> Currently, there are no classification methods that classify fingerprints



Figure 5. Result of palatal rugae intraoral images with clear boundaries



Figure 6. Angle boundary to determine the direction pattern classification

according to their direction. Therefore, this study classified thumbprints using an adaptation of Carrea's classification. First, the thumbprints were rotated 90 degrees to the midline of the body. Then, the direction group was determined by drawing a line from the center of the finger (core) to the edge of the finger (delta). (Figure 4).

ImageJ version 1.52a open source image processing software was used to identify the direction of palatal rugae and thumbprint patterns.<sup>23</sup> This software was used to process intraoral palatal rugae images to obtain the final result, which was an image of palatal rugae with a distinct border. First, the image of palatal rugae was converted into an 8-bit image and applied in approximately 85% - 90% threshold to remove artifacts in the image except for the palatal rugae. After that process, the filling color was removed so the border of the palatal rugae could be clearly seen (Figure 5). The thumbprint image direction pattern could be directly determined after being rotated 90 degrees to the midline of the body.

Direction	Palatal Rugae Direction Patterns				Thumbprint Direction Patterns			
	Right (n=1214)		Left (n=1212)		Right (n=191)		Left (n=191)	
	Ν	%	Ν	%	N	%	N	%
AP	779	64.17	597	49.26	111	58.12	107	56.02
Р	185	15.24	325	26.82	6	3.15	2	1.05
PA	10	0.82	4	0.32	32	16.75	37	19.37
R	240	19,77	286	23.6	42	21.98	45	23.56

Table 1. Frequency distributions of the direction pattern of the palatal rugae print and thumbprint

Table 2. Analysis of the relationship between palatal rugae pattern and thumbprint direction pattern

	Palatal Rugae-Thumbprint	df	<b>X</b> <sup>2</sup>	p-value
	first palatal rugae - thumbprint	9	19.18	0.024*
Right Side	second palatal rugae - thumbprint	9	8.7	0.466
	third palatal rugae - thumbprint	9	4.86	0.846
	fourth palatal rugae - thumbprint	9	9.9	0.359
	fifth palatal rugae - thumbprint	9	4.78	0.853
	sixth palatal rugae - thumbprint	6	8.13	0.229
	seventh palatal rugae - thumbprint	6	7.84	0.250
Left Side	first palatal rugae - thumbprint	9	4.68	0.861
	second palatal rugae - thumbprint	6	36.72	0.000*
	third palatal rugae - thumbprint	9	7.18	0.618
	fourth palatal rugae - thumbprint	9	3.05	0.963
	fifth palatal rugae - thumbprint	6	3.9	0.690
	sixth palatal rugae - thumbprint	6	8.83	0.183
	seventh palatal rugae - thumbprint	4	9.38	0.052

\*significant (p < 0.05); df: degree of freedom;  $X^{2}$ : chi-square association

Using the ImageJ program, the direction patterns were analyzed based on the angular size formed by the intersection of the line of the direction of the palatal rugae print pattern and thumbprints with a line perpendicular to the median line. In this study, each palatal rugae (from the first until the last that appeared on the right and left side of the palate) and each thumb (right thumb and left thumb) were analyzed. The direction pattern was expressed as PA if the angle was  $+ 6 \circ to + 175 \circ$ , the direction pattern was expressed as AP if angle was  $-6 \circ to -175 \circ$ , while the direction pattern was considered random if more than one angle was formed (Figure 6).

The statistical tests used in this study were Cohen's Kappa test to determine the level of intra- and interexaminer agreements and Chi-square contingency table test for association analysis<sup>24,25</sup> of the direction patterns of the palatal rugae print and thumbprint. The level of significance was defined as p-value < 0.05. The effect size calculation used in this study was Cramer's V test. All statistical analyses were done using SPSS 25.0 software (IBM Corp. Released 2017. IBM SPSS Statistics for Windows, Version 25.0. Armonk, NY: IBM Corp.).

#### RESULTS

A total of 2426 palatal rugae patterns were observed from 193 participants (1214 on the right side and 1212 on the left side), and 382 thumbprint patterns were identified from 193 individuals. The intra-examiner and inter-examiner reliability for the two researchers was calculated by Cohen's Kappa test. Kappa statistics revealed very good intra-examiner ( $\kappa = 0.95$ ) and inter-examiner agreement ( $\kappa = 0.94$ ) in measuring the number of rugae and direction pattern of the palatal rugae and thumbprints.

AP direction was the most common direction pattern among right palatal rugae (64.17%) and left palatal rugae (49.26%); and in thumbprints on the right hand (58.12%) and the left hand (56.02%). (Table 1)

Chi-square contingency table test (p-value of < 0.05 with a 95% confidence interval) was used for association analysis of the palatal rugae print direction

Palatal Rugae-Thumbprint	df	<b>X</b> <sup>2</sup>	p-value	Cramer's V	Value of Effect Size
First right palatal rugae - right thumbprint	9	19.18	0.024*	0.181	Small
second left palatal rugae - left thumbprint	6	36.72	0.000*	0.332	Medium

Table 3. Effect size analysis of the significant association between palatal rugae and thumbprint direction patterns

\*significant (p < 0.05); df: degree of freedom;  $X^{2}$ : chi-square association

patterns from first until seventh on the right side and left side with thumbprint direction patterns for the right and left hands. Results are shown in Table 2.

As shown in Table 2, there was a significant association between the first right palatal rugae and the right thumbprint (p-value = 0.024) and between the second left palatal rugae and the left thumbprint (p-value = 0.000). To show the magnitude of the effect from the significant association found in this study, Cramer's V test was used to calculate effect size (Table 3). According to Cohen (1988), the effect size of Cramer's V test was classified as large effect (Cramer's V result  $\geq$ 0.5), medium effect (Cramer's V result  $\geq$  0.3), and small effect (Cramer's V result  $\geq 0.1$ ).<sup>26,27</sup> Therefore, as shown in Table 3, the effect size of the association between the first right palatal rugae and the right thumbprint showed a medium effect size (Cramer's V = 0.332) and between the second left palatal rugae and the left thumbprint showed a small effect size (Cramer's V = 0.181).

#### DISCUSSION

This study used digital image processing techniques with the aim of reducing human error and the subjectivity factor of researchers.<sup>28</sup> The method for the direction pattern used as a reference was Carrea's classification. The use of Carrea's classification was for the purpose of producing more homogeneous results. This study was also conducted on one sub-racial species, the Deutero-Malay sub-race as the majority sub-race in Indonesia, to obtain more homogeneous results due to the unique characteristic of palatal rugae in different sub-races.<sup>2,9,29–31</sup> Analysis according to gender and certain age groups was not done in this study, because several recent studies showed that palatal rugae did not have significant differences for gender<sup>32–34</sup> and age group.<sup>4,35</sup>

Palatal rugae have been proven to be more than capable as an ideal identification method compared with other methods (e.g., fingerprints and DNA), due to their resistance to trauma, exposure to high temperature, and the decomposition process. Also, no special and expensive equipment is needed to identify palatal rugae.<sup>4,5,10,12</sup> A limitation of palatal rugae as an identification method is the lack of antemortem data and absence of a standardized identification method,<sup>1,4</sup> therefore, data acquired from palatal rugae need to be connected with data from fingerprints that is available from antemortem data, is easily accessible, and already has a standardized identification method.<sup>15,16</sup>

This study focused on finding the association between palatal rugae and thumbprints using direction pattern classification with individuals from Deutero-Malay sub-races. Most of the direction patterns in the Deutero-Malay sub-race found in this study were AP (right palatal rugae 64.17%, left palatal rugae 49.26%, right thumbprints 58.12%, and left thumbprints 56.02%). The results of this study indicate a significant association between the palatal rugae prints and thumbprints in terms of the direction pattern. An association with small effect size was found between first right palatal rugae and the right thumbprint (p-value = 0.024; Cramer's V = 0.181) and with medium effect size between second left palatal rugae and the left thumbprint (p-value = 0.000; Cramer's V = 0.332). There were no other studies with the same method found in the current medical literature to support or compare these findings. Several studies have been conducted focusing on finding the relationship between fingerprints and lip prints or fingerprints and the type of malocclusion.<sup>38-40</sup>

In 2012, Wichnieski, et al. conducted a study to find the association between thumbprints and palatal rugae based on Carrea's classification for palatal rugae and Vucetich's classification<sup>16</sup> for thumbprints.<sup>2</sup>

<sup>1</sup> Wichnieski and colleagues did not perform analysis according to gender and age groups as in this study, but they used a maxillary cast model to identify palatal rugae and thumbprints by making an impression on paper using black pigment ink.<sup>21</sup> They found no significant association between thumbprints and palatal rugae prints.<sup>21</sup> The different results in the Wichnieski, et al. study compared with our study may be due to differences in data processing techniques and classification methods. Until now, no other study has examined the association between palatal rugae and fingerprints.

The significant association found in this study is limited to the Deutero-Malay sub-race and has not been analyzed in other sub-races. Association testing in this study was linear between the right palatal rugae and right thumb and between the left palatal rugae and left thumb, so further research is needed to determine the relationship between these two variables using crosslinking analysis (right side with left side and vice versa).

Now that an association between palatal rugae pattern and fingerprint direction pattern has been found, it is expected that additional studies will examine other aspects of the association between palatal rugae and fingerprints. Aspects such as shape and size, the association between palatal rugae and fingerprints other than thumb, and data from other sub-races with further genetic and mathematical studies can contribute to new breakthroughs in forensic identification.

#### CONCLUSION

There is an association with small effect size between first right palatal rugae and right thumbprint (p-value = 0.024; Cramer's V = 0.181) and with medium effect size between second left palatal rugae and left thumbprint (p-value = 0.000; Cramer's V = 0.332) in individuals of the Deutero-Malay sub-race. This association can be used to develop a new alternative method to identify individuals in forensic science.

#### **CONFLICT OF INTEREST**

The authors declare no conflict of interest on the publication of the research.

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