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Investigation of Palatal Rugoscopy for Forensic Human Identification

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Abstract

Human identification is critical to the field of forensic science as well as in many sub-disciplines, including forensic pathology, forensic anthropology, and forensic odontology. While few widely-accepted methods of identification dominate the discipline (primarily fingerprint and dental record analysis), the study of palatal rugae patterns (rugoscopy) is an emerging tool in human identification. Some studies suggest that patterns of the palatal rugae are an individualizing characteristic among humans. While the use of rugoscopy for identification has been explored as an identifying marker in the dental and orthodontic communities, its use for forensic applications is not widely recognized. Also, while some literature is available about global populations, American studies of palatal rugae are quite limited.

In this research, multiple palatal rugae patterns were examined and classified, and attempts were undertaken to individualize the patterns observed. Using 76 images of palatal rugae patterns (including 60 images of dental casts and 16 intraoral images), the rugoscopic identity was calculated for each set of patterns and affirmed the individualizing nature of palatal rugae patterns. Additionally, a new, forensically-focused classification system was proposed using shape, length, and number of rugae as parameters. This research also investigated intraoral imaging and the creation of alginate impression records to determine the most optimal method for saving palatal rugae patterns from unidentified human remains (UHR) for further analysis. It may be concluded that palatal rugae patterns can be used for postmortem forensic identification in addition to existing methods, or as a substitute when such other methods may not be viable or available to establish human identity.

Introduction and Background

Methods of identification of human remains have evolved over time. While genetic (DNA) testing is a powerful tool for identifying an unknown decedent, it is expensive, time-consuming, and labor intensive. Additionally, recovering a DNA profile from human remains does not guarantee a positive identification, i.e., a DNA profile provides no context unless there are direct reference samples and/or family reference samples available for comparison. For these reasons, methods such as fingerprint identification and odontological comparisons are the initial approaches used for identification of human remains in forensic casework. However, while reliable, these methods of identification do have inherent limitations which can hinder the process of identifying human remains. Analysis of fingerprints and friction ridge detail for human identification has become ubiquitous due to its individualizing characteristics and permanence throughout life; however, friction ridge details can be obscured intentionally by lacerating or burning the skin, or unintentionally when the skin comes into contact with abrasive chemicals or fire. Moreover, fingerprints are not an option if the recovered human remains are in an advanced state of decomposition.

Palatal rugae (also referred to as palatine rugae) are transverse, elevated mucosal folds that consist of dense fibrous tissue located on the hard palatal surface of the upper mouth. Palatal rugae appear *in utero* three months after conception, and their irregular pattern stabilizes during adolescent years, becoming a stable (i.e., unchanging, permanent) marker for identification purposes. Rugoscopy, or palatal rugoscopy, is the study of palatal rugae for use in the process of postmortem human identification. Unlike friction ridge detail on fingers and toes, palatal rugae can be protected from extreme heat and trauma due

to their unique location in the human body. This protection is afforded by the cheeks, lips, teeth, and tongue, as well as by the bone comprising the maxilla and mandible. Therefore, in the event of complete burning of a decedent where all friction ridge detail is lost, an identification could potentially be made using palatal rugae patterns if the features of the mouth were able to preserve the characteristics of the folds.

Currently, some studies exist which attempt to determine the individualizing nature of palatal rugae patterns, or to suggest that rugoscopy can be used in postmortem human identification. However, most of these limited studies suggest the application of rugoscopy for dental, odontological, or orthodontic purposes -- not for forensic human identification. This study attempted to: 1) affirm the individualizing nature of palatal rugae impressions, and 2) investigate techniques to incorporate rugoscopy into the process of forensic human identification. The latter involved using pattern collection methods to propose comprising a database of palatal rugae patterns, similar to the Automated Fingerprint Identification System (AFIS), which is currently in use for forensic human identification using analysis of friction ridge detail.

Literature Review

In "Stability of Palatal Rugae as a Forensic Marker in Orthodontically Treated Cases" by Ali et al., researchers analyzed the potential for palatal rugae pattern changes in individuals who underwent treatment with braces, palatal expanders, or non-wire retainers. The study concluded that the lengths of the second and third rugae (out of three in total) were reduced following tooth extraction, the third rugae length was increased following the use of a palatal expander; however, in all other cases of orthodontic treatment, the

palatal rugae patterns remained constant. In order to classify palatal rugae, Ali et al. used length measurements and three different shape distinctions (curved, straight, and wavy) during the analytical portion of the research.

In "The Evidence of the Rugoscopy Effectiveness as a Human Identification Method in Patients Submitted to Rapid Palatal Expansion," Barbieri et al. focused solely on the use of palatal expanders and its correlation to rugae pattern morphological changes as a result of the expansion treatment. Similar to the research conducted by Ali et al., Barbieri et al. discussed possible discrepancies in palatal rugae positioning and shape both before and after orthodontic treatment. Conclusions from the research stated that rugae patterns remained unchanged following treatment with a palatal expander, and that identification of an individual using known impressions prior to expansion treatment would still be possible. Classification of rugae patterns in this study differed from the system employed by Ali et al. In this study, rather than being classified by length and basic shape, Barbieri et al. used ten different shape distinctions: period, straight line, curve, angle, closed curve, sinuous, bifurcation, trifurcation, broken, and anomalous. This classification system is known as the Santos classification model, which is loosely based on Juan Vucetich's classification system for fingerprints. Using the Santos model, in which each of the shape distinctions is assigned a number ranging from zero to nine, Barbieri et al. were able to calculate the *rugoscopic identity* of each subject. *Rugoscopy identity* was defined as the measure of variation in each of the individual rugae shapes on the entire palatine surface.

In "Establishing Identity Using Cheiloscopy and Palatoscopy" by Caldas et al., the authors review techniques of cheiloscopy (the study of lip grooves) and palatoscopy

(another term for rugoscopy, or the study of palatal rugae) to determine advantages and disadvantages of existing classification systems for identification. The authors concluded that palatal rugae may not be as useful as fingerprint identification for suspect linkage to crime scenes due to its position on the body (i.e., which has limited accessibility); however, using rugae patterns to identify victims is a viable (as well as valuable) resource for forensic analysts and investigators. Caldas et al. discussed eight different classification systems (including the Santos model previously mentioned) and examined the benefits and limitations of each system/model, as some are more comprehensive than others. Caldas et al. also referred to the use of stereoscopy as a means to record rugae patterns in order to provide a three-dimensional image of rugae anatomy; this includes the shape, pattern, and length of palatal rugae.

In "The Heritability of Palatal Rugae Morphology Among Siblings," Chong et al. challenged the individual nature of palatal rugae anatomy, pattern, and shape by comparing rugae morphology between siblings, citing that the greater the genetic similarities between two people, the higher the probability will be that palatal rugae patterns are highly similar. This research -- which considered length, shape, direction, and potential branching of the rugae -- concluded that no two siblings exhibited identical rugae patterns. This finding affirmed the individual nature of palatal rugae, although it was noted that many similarities between patterns in siblings existed. The study examined the palatal rugae patterns of 81 pairs of young Malaysian siblings, and it was also suggested that different shapes of rugae are more common in certain nationalities than others (which has important implications for databasing). Three-dimensional imaging and plaster casting were used to make impressions of the patterns, which were then analyzed using computer software.

In "Rugae Patterns as an Adjunct to Sex Differentiation in Forensic Identification," Gaikwad et al. identified and analyzed gender differences in palatal rugae patterns among 600 dental casts of palatal rugae (total n=600; 260 males and 340 females). The researchers used 15 defined rugae characteristics (similar to the Santos method) to distinguish on a percentage basis how common each characteristic of rugae was in males versus females. The study concluded that the wavy pattern is the most common rugae pattern, and that while some branching was more common in females, there was no clear distinction between males and females. The study also concluded that palatal rugae are uniquely individualistic. The methodology of this study included making plaster casts (to form patent molds of rugae patterns) and did not use any digital imaging or computer enhancement.

In "Indication and Limitations of Using Palatal Rugae for Personal Identification in Edentulous Cases," Ohtani et al. investigated the use of palatal rugae patterns for identification in the case of identifying edentulous individuals (i.e., people who lack teeth). The experimental procedure for this research included taking 146 dental plaster casts from both edentulous dental patients as well as cadaver subjects and, once the casts were made, a group of 50 examiners were tasked to match the casts to pre-existing casts that were produced at an earlier time. This study had an interesting approach (using a panel of qualified examiners to associate identical rugae patterns) and the results were measured in correct matches, not in individuality. However, the study concluded that the accuracy of identification was close to 100%, suggesting that palatal rugae are reliable markers for individualization and identification.

In "Palatal Rugoscopy: Establishing Identity," Paliwal et al. compared palatal rugae patterns in two different Indian populations to consider any predominant patterns among the groups. This study focused more on classification than individualization of rugae for human identification. Similar to other studies, researchers used dental plaster casts of 60 subjects' rugae patterns. With these casts, Paliwal et al. used shape and branching characteristics to classify each subject's palatal rugae impression patterns. The study concluded that straight rugae were more common among males in one of the Indian regions, while wavy rugae were more common in the other Indian community examined. The authors also claim that the uniqueness of rugae patterns are "promising", yet no real comparison to determine individualization was made. Statistical analysis was also performed between the two groups for the chosen parameters to associate rugae shape and ethnicity of the individual.

In "Palatal Rugae Pattern in a Portuguese Population: A Preliminary Analysis," Santos and Caldas used rugoscopy methods to characterize rugae patterns and attempted to determine which of the three rugae are most important to making an individualizing identification using rugoscopy. Using frequency of rugae shapes analyzed from 50 different plaster casts, the authors concluded that straight rugae are most prevalent in the first rugae, and that sinuous rugae are most prevalent in the third rugae. Santos and Caldas also confirmed that dimorphism of rugae between males and females was not present, which was consistent with the study conducted by Gaikwad et al. (described previously). This study used the Basauri method of classification, which uses the following shapes for classification: point, straight, angle, sinuous, curve, circle, and polymorphous. This classification method is most similar to the Santos method (no relation to the author).

In "Conversion of Palatal Rugae Pattern to Scanable Quick Response Code in an Arabian Population," Syed et al. attempted to convert palatal rugae patterns into an alphanumeric code to generate a quick response (QR) code for each pattern, in an effort to investigate individuality and sexual dimorphism. In total, 256 plaster casts were taken and subsequently photographed to analyze rugae patterns, and each characteristic was assigned a letter (i.e., straight = a, curved = b, wavy = c, etc.). With these alphanumeric codes, QR codes were generated to represent each pattern. It was concluded that none of the 256 QR codes matched another exactly. The authors also concluded that men had a larger number of rugae than women, but dimorphism in regards to individual shapes and characteristics was not prevalent in the study samples. This research used a combination of plaster casting and photography to ensure proper analysis of rugae patterns, and incorporated coding and generated technology to prove the individuality of palatal rugae structural patterns.

In "Assessment of Palatal Rugae Pattern and Its Significance in Orthodontics and Forensic Odontology," Umme Romana et al. compared the shape of rugae and how maxillary expansion treatment affected changes in the shape and position of rugae patterns. Using 15 pairs of pre- and post-treatment plaster casts of palatal rugae pattern impressions, the authors identified similarities and differences between rugae markings and landmarks before and after maxillary expansion treatment with palate expanders. The study concluded that although inter-rugae distance had a significant difference between the pre- and post-treatment casts, palatal rugae are a stable landmark that can be used in forensic identification "for postmortem resistance and stability." However, the authors admitted that they did not consider the length of rugae as a testing parameter, choosing to analyze distance between the first two rugae instead.

Materials and Methods

Classification of palatal rugae using the Santos method

To determine potential individualizing characteristics of palatal rugae patterns, the Santos Method was employed using 16 intraoral images of palatal rugae patterns and 60 images of dental castings which contained palatal rugae impressions. The Santos Method uses palatal rugae morphology in order to appropriately classify the patterns for identification and individualization. The Santos Method separates palatal rugae into four categories based on their position in relation to the incisive papilla, which is the raised ridge characteristic of the hard palate located at the most anterior position of the hard palate, in the center of the palatal space, immediately posterior to the central incisors of the maxilla. The categories are: 1) initial, which is the most anterior ruga to the right of the incisive papilla (in anatomical position); 2) complementary, which are the remaining rugae to the right of the incisive papilla; 3) subinitial, which is the most anterior ruga on the left side of the incisive papilla; and 4) subcomplementary, which are the remaining rugae on the left side of the incisive papilla. The rugae patterns are then represented by a letter or number in the classification system, i.e., letters for initial and subinitial rugae, and numbers for complementary and subcomplementary rugae **(Table 1)**. The names that represent each of the palatal rugae pattern shapes are listed using their original Portuguese-language names, as first introduced by Santos in 1954. Only the two most anterior rugae on either side of the incisive papilla were considered for this classification.

Table 1. Palatal rugae classification using the Santos method

Palatal rugae pattern shape	Initial and subinitial rugae representation	Complementary and subcomplementary rugae representation
Ponto (period)	P	0
Reta (straight line)	R	1
Curva (curve)	C	2
Ángulo (angle)	A	3
Curva fechada (closed curve)	Cf	4
Sinuosa (sinuous)	S	5
Bifurcada (bifurcate)	B	6
Trifurcada (trifurcate)	T	7
Quebrada (broken)	Q	8
Anômala (anomalous/other)	An	9

Once all rugae patterns were classified using the Santos method, the *rugoscopic identity (RI)* of each of the patterns provided in the intraoral and casting images was calculated. These calculations were used to demonstrate the individuality of palatal rugae patterns, and their identifying ability. *Rugoscopic identity* was calculated using the following formula:

$$\textbf{RI} = \frac{\textbf{Initial complementary}}{\textbf{Subinitial subcomplementary}}$$

Development of a forensic classification system of palatal rugae

Few classification systems for palatal rugae exist. Methodology for classification varies in what measure(s) of rugae are being used for classification, including shape, number, and dimensions (e.g., width, length). No current classification system for analysis of palatal rugae for forensic human identification incorporates all of the aforementioned measures. While friction ridge characteristics on fingers and toes do not incorporate length or width in basic classification methods, instances of minutiae are far more abundant in friction ridge detail than in palatal rugae ridge detail.

The advent of a comprehensive, forensically-centric classification of palatal rugae is critical for its implementation into human identification casework protocols (as well as its use in conjunction with existing identification methods). In order to fully incorporate all measures of palatal rugae, a cohesive classification approach is proposed in **Table 2**.

Table 2. Overview of proposed (new) classification system for palatal rugae

Palatal Rugae Pattern Shape	Length	Width
Angle (AN) Bifurcation (BI) Broken ruga (BR) Circle (CI) Convergence (CO) Curve (CU) Dot (DO) Sinuous (SI) Straight line (SL) Trifurcation (TR)	Horizontal length in millimeters (mm) from medial end to distal end, followed by the letter "L"	Vertical width in millimeters (mm), followed by the letter "W"

In addition to pattern shape, length, and width, the total number of rugae will be indicated by row (from anterior to posterior) through an alphanumeric code, similar to the National Crime Information Center (NCIC) classification system for friction ridge characteristics of fingerprints. This code will indicate the most anterior ruga on the right side of the hard palatal surface, continue along the right side of the palate, and then proceed with the most anterior ruga on the left side of the hard palatal surface, continuing with all remaining rugae on the left side of the mouth. A forward slash will separate the right side of the mouth from the left side.

To demonstrate, an individual may have a palatal rugae classification under this new system as follows: **SL8.2L2.3W SI6.5L2.9W CU5.5L1.2W AN4.4L0.8W / SL7.9L2.2W SL6.3L2.5W SL4.6L1.6W AN4.9L1.2W.** This code would be interpreted as: 1) on the right side of the hard palatal surface from anterior to posterior, the subject has

a straight line ruga with a length of 8.2 millimeters and width of 2.3 millimeters; a sinuous ruga with a length of 6.5 millimeters and width of 2.9 millimeters; a curve ruga with a length of 5.5 millimeters and width of 1.2 millimeters; and an angle ruga with a length of 4.4 millimeters and width of 0.8 millimeters, and 2) on the left side of the hard palatal surface from anterior to posterior, the subject has a straight line ruga with a length of 7.9 millimeters and width of 2.2 millimeters; a straight line ruga with a length of 6.3 millimeters and width of 2.5 millimeters; a straight line ruga with a length of 4.6 millimeters and width of 1.6 millimeters; and an angle ruga with a length of 4.9 millimeters and width of 1.2 millimeters.

Through the use of this proposed classification system, all aspects of the palatal rugae which can be identified and compared to another sample, or database of samples, can be considered in comparison analysis. It is still suggested to use an additional visual form of analysis (such as intraoral digital imaging) to affirm individuality in the event of a significant or total match. Visual examination can assist in classification when used in conjunction with this proposed classification system.

Collection of palatal rugae pattern impressions

To investigate ideal methods for collecting palatal rugae patterns for further analysis, two approaches were used to save records of rugae patterns and morphology -- intraoral imaging and dental impression taking. For intraoral imaging, an IP68 5.5mm 1080P Wireless Endoscope (Solar-Power brand) was paired to a smartphone in order to capture color images from inside the mouth to record palatal rugae patterns. Images were

positioned such that the anterior portion of the hard palate was positioned at the top of the frame of the image.

For dental impression taking, alginate impression material was used to make impressions of features of the maxilla and hard palate. Using Color Change Fast Set Dust-Free Alginate Powder (Cavex), intraoral impressions were taken to capture palatal rugae patterns as well as the length, width, and depth of the rugae. To create the mixture, 7 grams of alginate powder were mixed with 15 milliliters of room temperature water, and loaded into a maxillary impression tray (PlastCare USA). Once the alginate-water mixture was loaded into the impression tray, the tray was placed into the subject's mouth and pressed firmly against the maxillary teeth and hard palatal surface. The tray was left in the subject's mouth for approximately 30 seconds, at which time the alginate mixture changed color from light purple to white (indicating that setting of the alginate was complete). The tray was then gently removed from the subject's mouth and the impression (casting) was removed from the dental tray.

Results

Table 3 details the *Rugoscopic Identities* (RIs) of the 16 palatal rugae patterns evaluated through intraoral imaging, and **Table 4** depicts the RI of 60 palatal rugae patterns from casting images.

Table 3. *Rugoscopic Identities* (RIs) of 16 palatal rugae patterns from intraoral imaging

Subject	Rugoscopic Identity (RI)
1	$\frac{A_8}{B_5}$
2	$\frac{C_1}{T_4}$
3	$\frac{B_1}{C_1}$
4	$\frac{B_1}{T_1}$
5	$\frac{A_1}{B_5}$
6	$\frac{An_8}{An_5}$
7	$\frac{R_6}{R_1}$
8	$\frac{An_5}{S_4}$
9	$\frac{R_0}{T_3}$
10	$\frac{An_4}{R_7}$
11	$\frac{R_1}{B_1}$
12	$\frac{C_0}{B_1}$
13	$\frac{S_1}{R_3}$
14	$\frac{B_1}{R_1}$
15	$\frac{R_2}{A_1}$
16	$\frac{B_6}{B_3}$

Table 4. *Rugoscopic Identity* (RI) of 60 palatal rugae patterns from casting images

Subject	RI	Subject	RI	Subject	RI	Subject	RI
1	$\frac{P_5}{A_8}$	16	$\frac{B_1}{An_5}$	31	$\frac{B_0}{A_0}$	46	$\frac{R_1}{B_1}$
2	$\frac{R_0}{A_3}$	17	$\frac{B_1}{An_0}$	32	$\frac{P_0}{S_0}$	47	$\frac{B_0}{R_0}$
3	$\frac{A_0}{R_0}$	18	$\frac{A_8}{A_0}$	33	$\frac{B_5}{C_1}$	48	$\frac{R_8}{An_1}$
4	$\frac{R_4}{R_2}$	19	$\frac{R_1}{A_1}$	34	$\frac{B_1}{R_0}$	49	$\frac{P_1}{S_0}$
5	$\frac{R_3}{A_0}$	20	$\frac{R_0}{B_1}$	35	$\frac{B_5}{S_1}$	50	$\frac{An_8}{An_1}$
6	$\frac{A_3}{Q_5}$	21	$\frac{B_8}{An_0}$	36	$\frac{R_5}{R_1}$	51	$\frac{A_8}{C_0}$
7	$\frac{R_1}{R_6}$	22	$\frac{B_3}{A_3}$	37	$\frac{A_5}{S_5}$	52	$\frac{T_8}{R_8}$
8	$\frac{An_1}{A_1}$	23	$\frac{B_5}{B_2}$	38	$\frac{C_0}{A_5}$	53	$\frac{P_2}{P_0}$
9	$\frac{B_8}{B_3}$	24	$\frac{R_5}{Q_1}$	39	$\frac{R_8}{A_5}$	54	$\frac{B_6}{S_8}$
10	$\frac{B_9}{B_9}$	25	$\frac{A_6}{A_0}$	40	$\frac{Cf_8}{An_0}$	55	$\frac{S_6}{R_8}$
11	$\frac{A_1}{C_1}$	26	$\frac{R_1}{R_1}$	41	$\frac{B_3}{A_1}$	56	$\frac{Q_0}{A_1}$
12	$\frac{A_3}{A_0}$	27	$\frac{B_9}{A_8}$	42	$\frac{R_1}{S_5}$	57	$\frac{R_1}{S_1}$
13	$\frac{A_1}{R_0}$	28	$\frac{B_3}{S_8}$	43	$\frac{P_1}{An_0}$	58	$\frac{R_6}{R_0}$
14	$\frac{R_9}{A_0}$	29	$\frac{A_5}{B_0}$	44	$\frac{B_8}{R_8}$	59	$\frac{B_5}{B_1}$
15	$\frac{R_6}{P_3}$	30	$\frac{B_8}{B_6}$	45	$\frac{B_9}{R_5}$	60	$\frac{An_6}{An_1}$

Comparing the *Rugoscopic Identities* (RIs) of 76 different palatal rugae patterns, and only taking into account the two most anterior rows of rugae, there were 75 unique identities. The most common rugae pattern shape found in the anterior row (initial and subinitial) was a straight line, occurring once or twice in the anterior row in 25% of the patterns, followed by a bifurcation, occurring once or twice in the anterior row in 24.3% of the analyzed patterns. The most common complementary and subcomplementary rugae

pattern shape, (i.e., the rugae patterns found in the second row of rugae) are 1) a straight line, which occurred once or twice in the second row of rugae in 29.6% of the patterns, and 2) a point, which occurred once or twice in the second row of rugae in 19.7% of the patterns. Closed curves and trifurcations were the least common rugae patterns among all rugae on both rows. Each only occurred five times each among all 304 rugae that were examined. Points and broken ridges were much more common in the second row of rugae than in the first row, while bifurcations were far more prevalent in the most anterior row than in any subsequent row. Rugae patterns were classified as anomalous if they did not fall into the other eight major categories, which included circles with and without enclosures, and hook shaped rugae that were not similar to other curve or closed curve patterns. **Table 5** details the occurrences of each ruga shape in the set, using the English language version of the Santos classification method designations. Percentages were calculated based on total rugae from each row, which is double the total number of rugae patterns (or 152 rugae in each row).

Table 5. Occurrences of different ruga shapes during Santos classification ($n = 304$)

Ruga shape	Occurrences in the first row of rugae	Percentage of total ($n = 152$)	Occurrences in the second row of rugae	Percentage of total ($n = 152$)
Period	7	4.61%	30	19.74%
Straight line	38	25.0%	45	29.61%
Curve	7	4.61%	4	2.63%
Angle	29	19.08%	13	8.55%
Closed curve	1	0.66%	4	2.63%
Sinuous	11	7.24%	20	13.16%
Bifurcate	37	24.34%	10	6.58%
Trifurcate	4	2.63%	1	0.66%
Broken	3	1.97%	20	13.16%
Anomalous	15	9.87%	5	3.29%

The only *Rugoscopic Identity* that was observed in multiple subjects was an $\frac{R_1}{B_1}$, which represents a straight line initial ruga, a straight line complementary ruga, a bifurcation subinitial ruga, and a straight line subcomplementary ruga. **Figure 1** and **Figure 2** show the two samples with this RI. No other subjects from either the intraoral imaging samples or the dental casting image samples possessed an identical rugoscopic identity. There was no evidence to suggest that the two samples with identical rugoscopic identities originated from the same person. Upon visual examination, it was observed that the rugae vary in both length and width, and in overall orientation on the hard palatal surface of the upper mouth. With the overall sample set of 76 palatal rugae patterns and using the Santos method for palatal rugae classification, it was determined that 98.7% of the rugoscopic identities were unique and individual.

Figure 1
Palatal rugae intraoral (Subject 11), which was classified with a *Rugoscopic Identity* (RI) of $\frac{R_1}{B_1}$

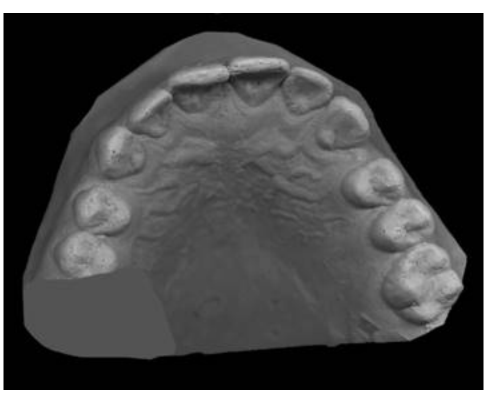

Figure 2
Palatal rugae casting from Subject 46, also classified with a *Rugoscopic Identity* (RI) of $\frac{R_1}{B_1}$

Figure 1 and Figure 2 represent the only instance of matching identities in rugae from two different individuals

Discussion

According to the results of the rugoscopic identity examination, it can be determined that palatal rugae pattern characteristics exhibit variation at levels that supports their use for individualization. Using the Santos method of classification, however, is mostly presumptive in the process of human identification, as only the morphological shape of each of the rugae are considered. Albeit presumptive, this examination suggested that even a preliminary method can speak volumes regarding identification, since there is no need to proceed further with analysis if an unknown palatal rugae pattern did not have the same rugoscopic identity as a known reference sample. Additionally, only the two most anterior rugae on either side of the incisive papilla were considered for this examination. As shown in the new and comprehensive forensic palatal rugae classification system, some individuals have three or four rows of palatal rugae, further asserting that this examination, which only considered two rows, can suggest that palatal rugae can be used to identify a person when a reference sample is available for comparison.

The creation of a forensic database of palatal rugae pattern information would greatly benefit and advance the field of palatal rugoscopy for forensic human identification. The new palatal rugae classification method which takes a comprehensive approach to all measurable aspects of palatal rugae, and its implementation into a database would provide another manner of identification as a complement to existing methods. Also, in the event that friction ridge detail is lost, by amputation, exposure to extreme temperatures, or any other event that would compromise the skin morphology of the fingertips, palatal rugoscopy could be used as a primary method of identification in place of fingerprint analysis. Palatal rugoscopy could also be used as an alternate method of identification to

DNA analysis, however, the palatal rugae are soft tissue, and will decompose prior to full skeletonization of the body, whereas DNA will persist in the osteocytes of bone beyond the late decomposition stage of dry decay and diagenesis.

For collection of palatal rugae patterns to use for further comparison or analysis, two different methodologies were investigated: intraoral digital imaging, and the collection of dental impressions using alginate powder. While the alginate impressions are helpful in visualizing and manually measuring dimensional characteristics, the difficulty in handling the time-sensitive alginate/water mixture while at a crime scene to collect an impression sample of a decedent would need to be managed well by an individual with dental or odontological training. **Figure 3** shows an alginate impression of the hard palatal surface, including palatal rugae characteristics. It is also imperative to be familiar with alginate mixing to ensure that no air bubbles are present in the mixture, as bubbles can inadvertently be misinterpreted or misrepresented as dot-shaped rugae. In addition, the alginate impressions produce a negative record of the teeth and hard palatal surface, which can be subject to distortion during analysis. The dental casts that were used for the imaging in the classification portion of this research was used with a different material and executed with a different method in order to produce a three-dimensional cast of the mouth, which would better enhance the characteristics of the palatal rugae. Dental plaster material is used to create dental casts, which differ from dental impressions in that castings are hard material, as opposed to an alginate impression which becomes a pliable material once set. The pliability of alginate impressions proves to be another disadvantage to its use for palatal rugae pattern analysis since it can easily be damaged through bending or otherwise overuse through handling, whether proper or improper. Persistent or repeated stretching of alginate

impression material, once it has set following intraoral implementation for rugae impression taking, could warp the patterns that the rugae leave in the alginate, thus misrepresenting the actual size and shape of the rugae in the mouth, which could lead to invalid or erroneous classification, and an incorrect identification.

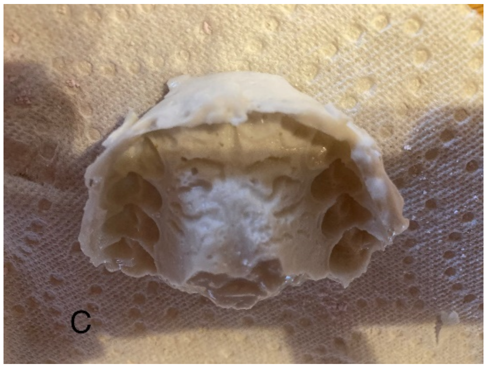

Figure 3
Alginate impression of palatal rugae *Pattern C*, containing negative images of the teeth and hard palatal surface characteristics, including palatal rugae

It was also observed that palatal rugae that have little depth will not develop in an alginate impression. Subjects who have palatal rugae that are smaller in size will not be able to fully insert their palatal rugae into the alginate impression material enough to produce a negative impression. **Figure 4** illustrates this disadvantage of alginate impression taking of palatal rugae characteristics.

Figure 4
Alginate impression of palatal rugae *Pattern B*, containing negative images of the teeth and hard palatal surface characteristics, lacking palatal rugae impressions due to the decreased thickness of the individual rugae

Alginate impressions, taken with a plastic dental tray, will also distort over time when removed from the plastic tray. This means, to ensure most accurate characteristics remain from the time of the impression, plastic trays cannot be re-used, and must remain with the impression, and cannot be separated. This could pose a financial burden for a municipal crime laboratory or police department that would need an exorbitant amount of

plastic trays if every unidentified decedent was fit with an alginate impression for the purposes of palatal rugoscopy.

On the other hand, digital intraoral imaging proved to be an effective manner for the collection of palatal rugae patterns for further analysis and comparison. Although two-dimensional imaging is all that can be produced through this method, it is efficient, cost-effective, and does not require much training. All intraoral images taken at dental offices for use in the classification portion of the methodology of this research were performed with dental mirrors to ensure photo quality and consistency; however, the use of a wireless endoscope paired to a smartphone proved to be a successful way to capture images of palatal rugae patterns. To improve context of the images, a scale can be added to the image in the same manner as crime scene imaging of other evidence, or forensic analysts can measure the dimensional characteristics of the individual rugae *in situ*. **Figure 5**, **Figure 6**, **Figure 7**, **Figure 8**, and **Figure 9** show results of intraoral image taking performed via the use of the wireless endoscope.

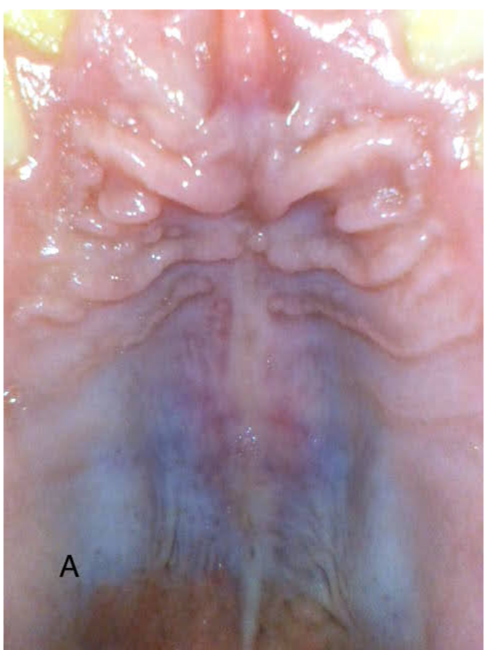

Figure 5
Digital intraoral image of palatal rugae *Pattern A* using a wireless endoscope

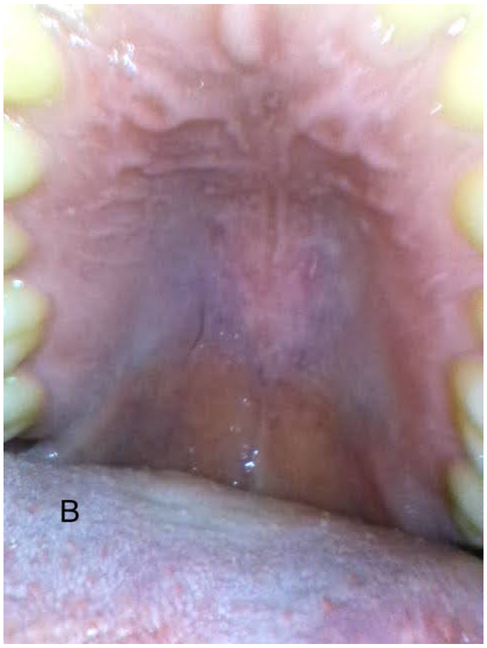

Figure 6
Digital intraoral image of palatal rugae *Pattern B* using a wireless endoscope

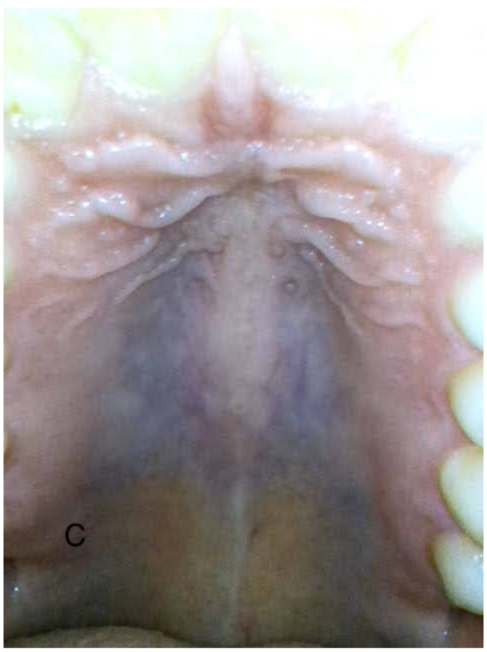

Figure 7
Digital intraoral image of palatal rugae *Pattern C* using a wireless endoscope

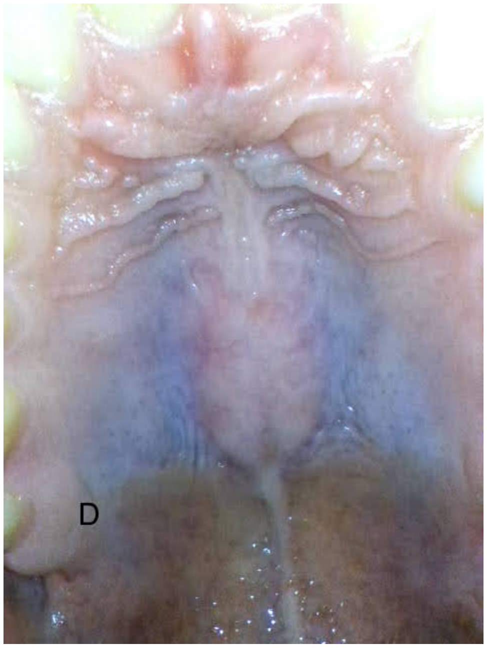

Figure 8
Digital intraoral image of palatal rugae pattern D using a wireless endoscope.

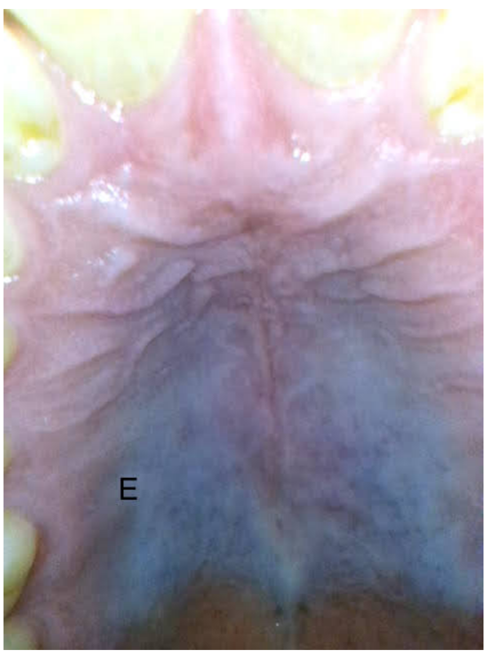

Figure 9
Digital intraoral image of palatal rugae pattern E using a wireless endoscope.

In contrast to digital intraoral images taken in a clinical setting for dental analysis, the images taken with the wireless endoscope were not uniform in nature, and varied in orientation slightly between each captured image. However, all images were taken with the anterior portion of the maxilla at the top portion of the frame of the image. This was to simulate collection at a crime scene, where dental or odontological tools are likely not

available to crime scene investigators, medicolegal death investigators, or forensic anthropologists. This is similar, in a sense, to a fingerprint examiner only being able to recover a partial print at a crime scene, which does not contain all of the friction ridge detail of the skin on the tip of the finger. However, in the case of intraoral imaging of palatal rugae using a wireless endoscope, the entirety of the pattern is depicted in the image, where analysis of morphology can take place. The only instance where palatal rugae patterns would be incomplete would be in the case of advanced decomposition (where the characteristics of the patterns would have already undergone severe modifications), or the rare instance of critical damage to the head, face, or mouth (which could damage or alter palatal rugae pattern characteristics and morphology). Specialized computer programs can enhance imaging for analysis if such a program were developed to assist in the advancement of forensic palatal rugoscopy for human identification. However, if it would assist rugoscopic analysts, the use of dental mirrors for more accurate image capture could be used. Due to its position in the mouth, palatal rugae cannot be exposed to ink and transferred to paper for further analysis in the same manner as friction ridge detail, so digital imaging along with three-dimensional analysis would be the most effective methods to categorize, classify, and separate different rugae pattern characteristics.

The determining factor for the advancement of palatal rugoscopy for forensic human identification is consistency with regards to individuality of patterns. This research concluded that, in this sample set, palatal rugae patterns -- when solely classified based on shape of the two most anterior rows of rugae -- are 98.7% unique. Preliminary studies into the individuality of palatal rugae have asserted similar claims. The use of the new classification system, which not only takes shape into account, but length, width, and the

totality of the rugae present on the hard palatal surface, can individualize palatal rugae morphology even further. A database, analogous to the Automated Fingerprint Identification System (AFIS), would be supported and will only improve the discipline of forensic palatal rugoscopy to allow it to become a standard for identification. The new classification system, which generates an alphanumeric code as an identifier, can be used to either include or eliminate certain individuals during the identification process (assuming a database of reference samples is available for comparison).

However, to properly ensure quality control when performing palatal rugae pattern analysis using the new classification method, analysts should work in concert in order to determine a classification for any or all palatal rugae. While shape of the rugae is more subjective than dimensional measures, there could still be disagreement in the perceived nature of the analytical characteristics of palatal rugae of which the classification system is based. This new classification method removes ambiguous distinctions, such as the Santos method's angle, curve, and closed curve shape designations, which all refer to the same rugae shape, and only differ depending on the corresponding angle that the bend in the ruga makes. This simplification does not translate to oversimplification or exclusion of certain pattern shapes, as this method also includes a measure of length and width, a measure that most of the other few palatal rugae classification methods do not include.

As previously explained, palatal rugoscopy can be used in conjunction with (or in place of) analysis of friction ridge detail or DNA analysis. Its individuality warrants it to be treated similarly as evidence to those methods.

Conclusion

Palatal rugae patterns, using morphological characteristics such as shape, number, width, and length, can be used for postmortem forensic identification in addition to existing

methods, or as a substitute to the other methods when such other methods may not be viable or available to establish human identity due to the individualizing nature of the ridge patterns and characteristics, as illustrated by basic classification methodology.

The creation of a new, comprehensive classification system for palatal rugoscopy takes into account all measureable and visually recordable features to provide a cohesive representation of pattern shape, size, and number of each palatal rugae present on the hard palatal surface of the mouth. Implementation into a database would further advance the field of forensic palatal rugoscopy to a ubiquitous standard for identification of unidentified victims or human remains.

It can also be concluded that alginate impression taking is not a reliable method to save palatal rugae pattern characteristics, due to its time sensitivity, negative image production, susceptibility to distortion, and necessity that the impressions must remain in the plastic dental trays to retain the integrity of the impression. Using intraoral digital imaging for comparison is a much more effective method for palatal rugae collection, and would be supported by a database for applying classification tactics for identification.

Acknowledgments

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References

Ali B, Shaikh A, Fida M. Stability of Palatal Rugae as a Forensic Marker in Orthodontically Treated Cases. *J Forensic Sci*. 2016;61(5):1351-1355. doi:10.1111/1556-4029.13129

Barbieri A, Scoralick R, Naressi S, Moraes M, Daruge E, Daruge E. The Evidence of the Rugoscopy Effectiveness as a Human Identification Method in Patients Submitted to Rapid Palatal Expansion. *J Forensic Sci*. 2013;58:S235-S238. doi:10.1111/j.1556-4029.2012.02263.x

Caldas I, Magalhães T, Afonso A. Establishing identity using cheiloscopy and palatoscopy. *Forensic Sci Int*. 2007;165(1):1-9. doi:10.1016/j.forsciint.2006.04.010

Chong J, Syed Mohamed A, Marizan Nor M, Pau A. The Heritability of Palatal Rugae Morphology Among Siblings. *J Forensic Sci*. 2020:786-788. doi:10.1111/1556-4029.14507

Gaikwad R, Kamble S, Rana R, Jain S, Gondivkar S, Bajad P. Rugae patterns as an adjunct to sex differentiation in forensic identification. *Stomatologija: Baltic Dental and Maxillofacial Journal*. 2019;21(3):79-82. PMID: 32108651

Ohtani M, Nishida N, Chiba T, Fukuda M, Miyamoto Y, Yoshioka N. Indication and limitations of using palatal rugae for personal identification in edentulous cases. *Forensic Sci Int*. 2008;176(2-3):178-182. doi:10.1016/j.forsciint.2007.09.002

Paliwal A, Wanjari S, Parwani R. Palatal rugoscopy: Establishing identity. *J Forensic Dent Sci*. 2010;2(1):27. doi:10.4103/0974-2948.71054

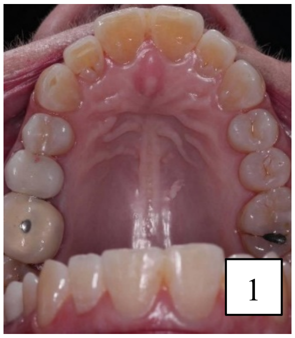
Santos C, Caldas I. Palatal Rugae Pattern in a Portuguese Population: A Preliminary Analysis. *J Forensic Sci*. 2011;57(3):786-788. doi:10.1111/j.1556-4029.2011.02016.x

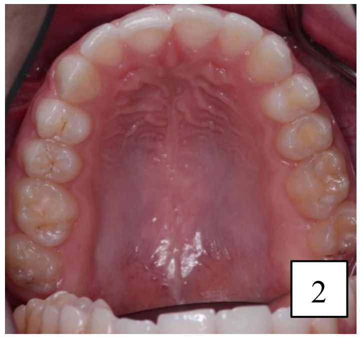
Syed S, Alshahrani I, Alshahrani A, Togoo R, Luqman M, Dawasaz A. Conversion of palatal rugae pattern to scanable Quick Response code in an Arabian population. *J Dent Sci*. 2016;11(3):253-260. doi:10.1016/j.jds.2016.02.004

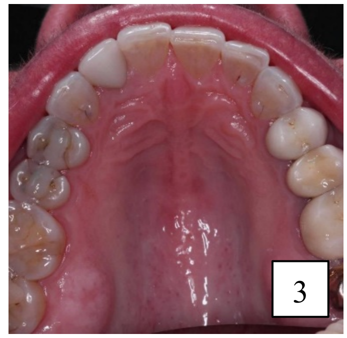
Umme Romana I, Shailaja A, Narayanappa G, Smitha T, Gowda N, Vedavathi H. Assessment of palatal rugae pattern and its significance in orthodontics and forensic odontology. *Journal of Oral and Maxillofacial Pathology*. 2018;22(3):430. doi:10.4103/jomfp.jomfp_190_18

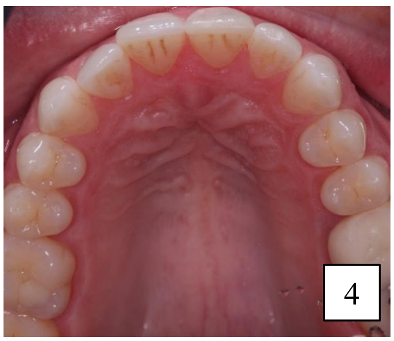
Appendix A

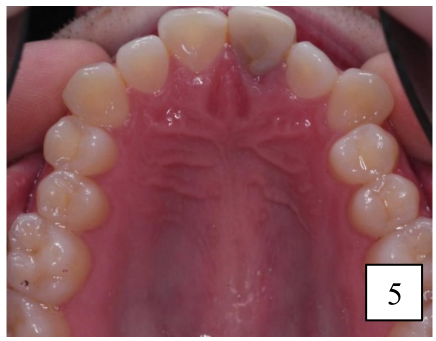
Digital intraoral images of palatal rugae used in this study (1-16)

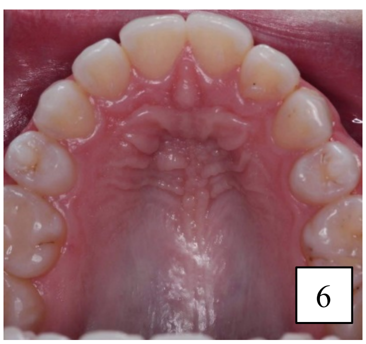


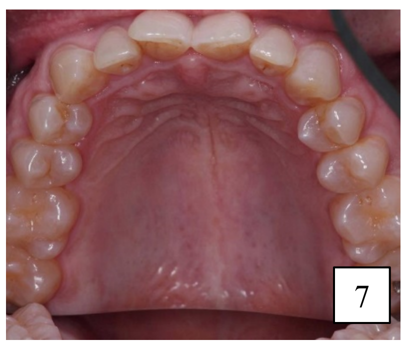


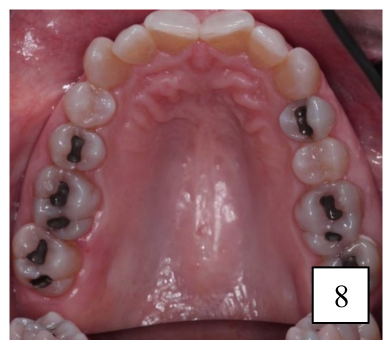


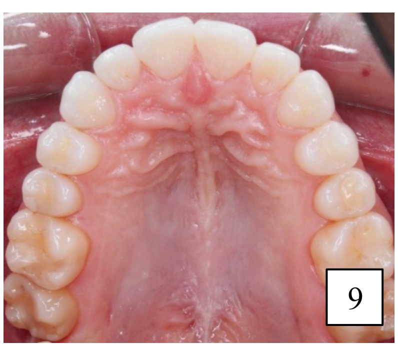


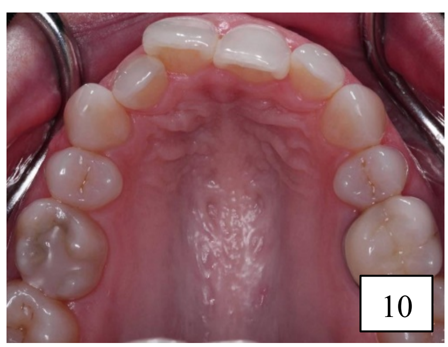


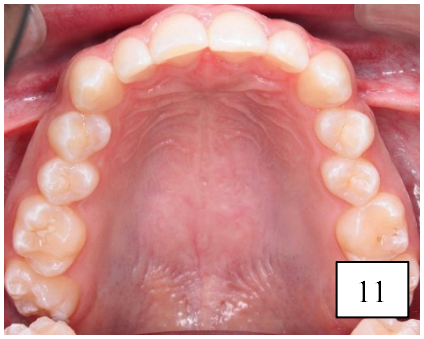








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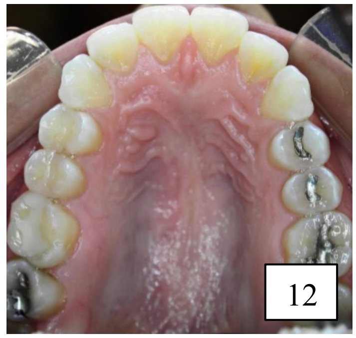
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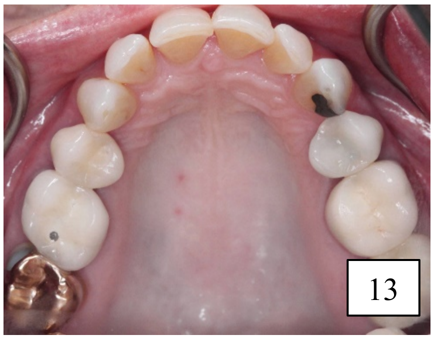
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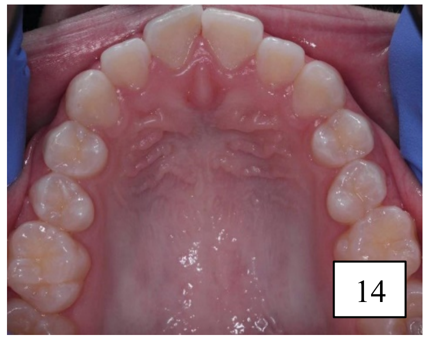
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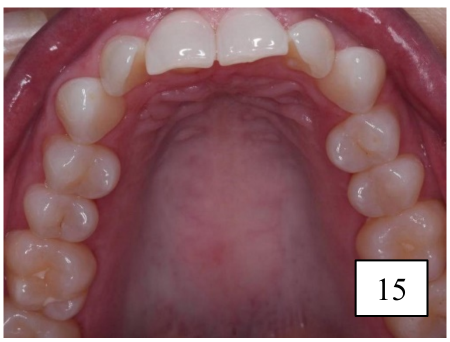
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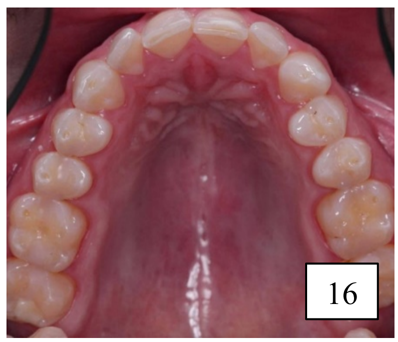
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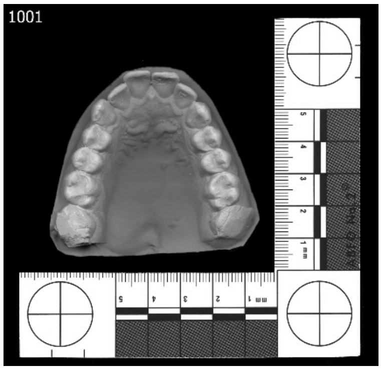
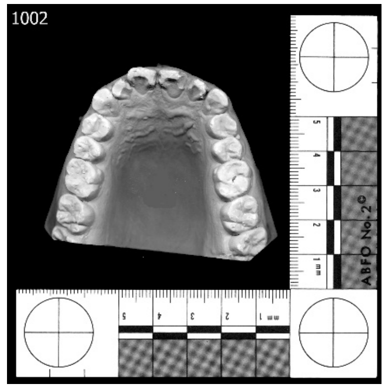
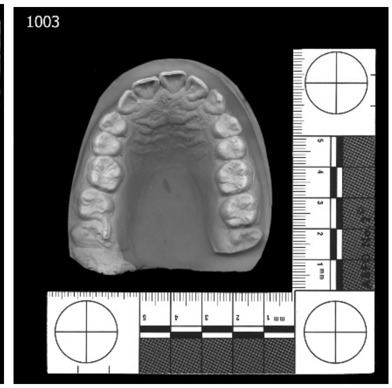
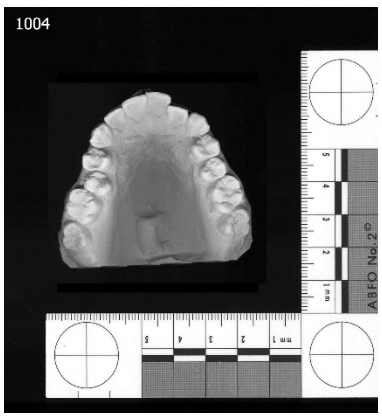
Appendix B

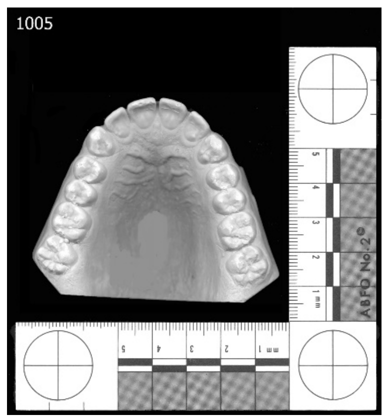
Images of palatal rugae castings used in this study (1-60)

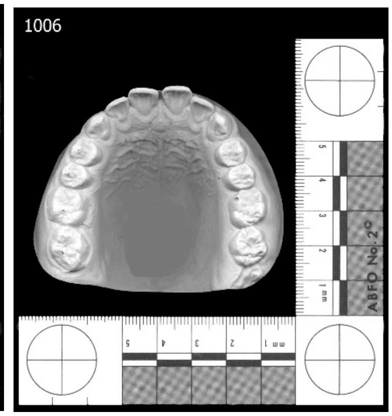


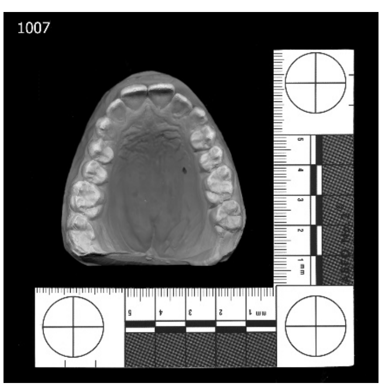


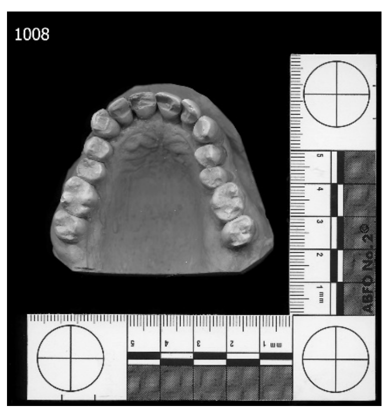


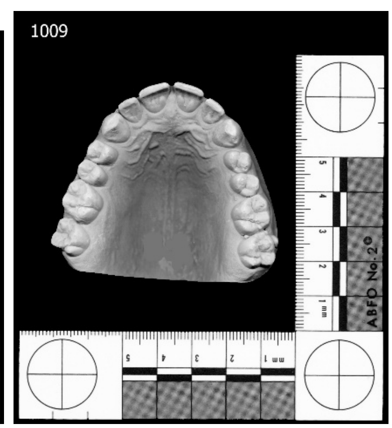


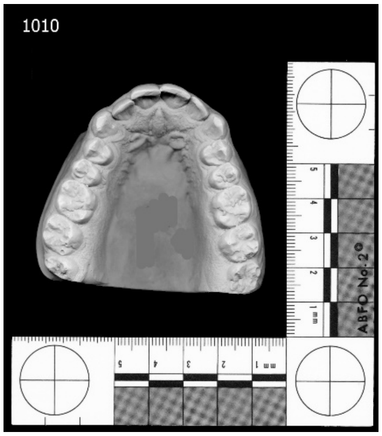








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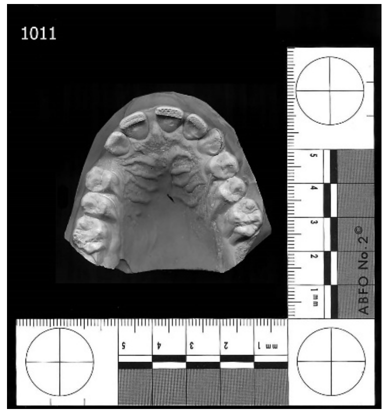
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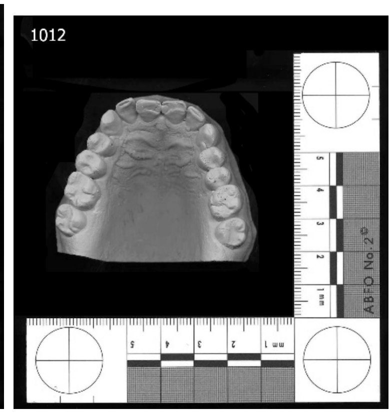
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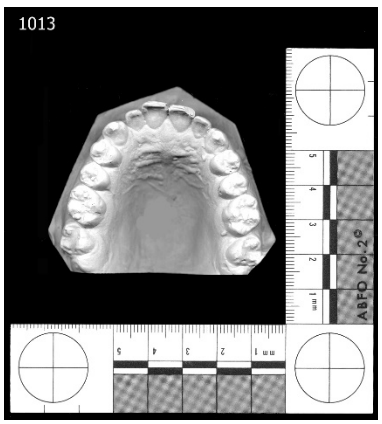
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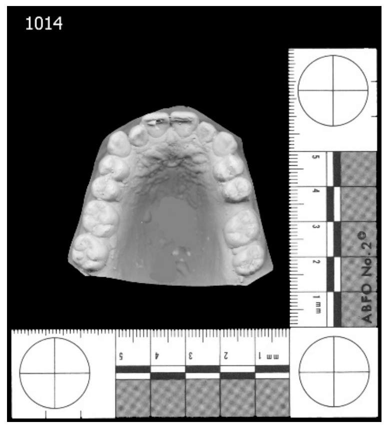
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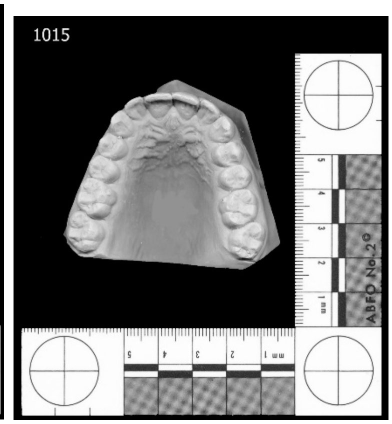
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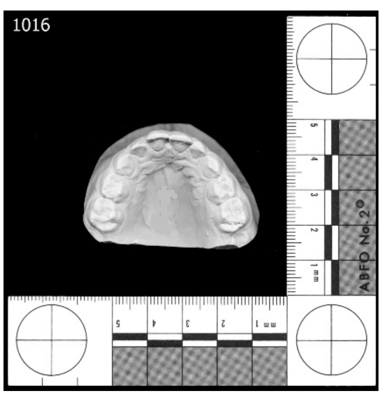
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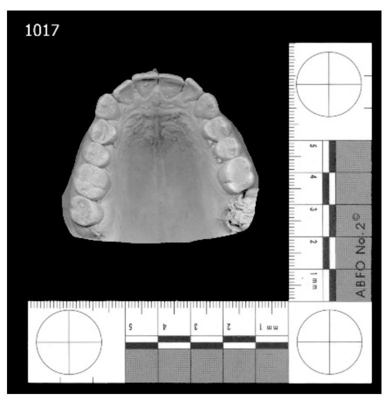
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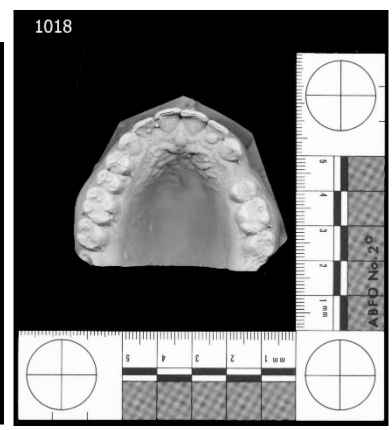
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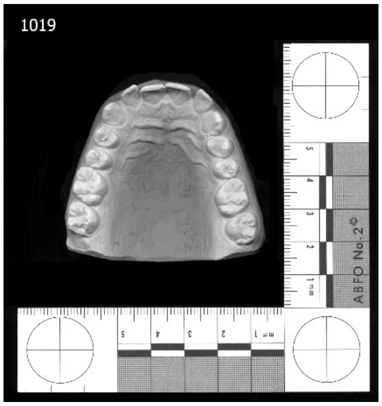
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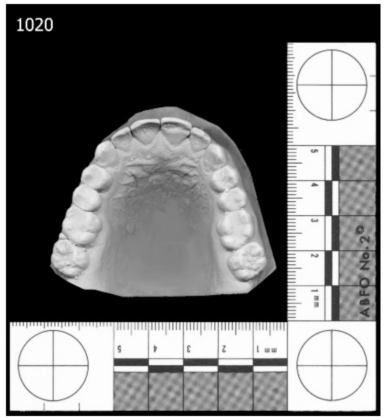
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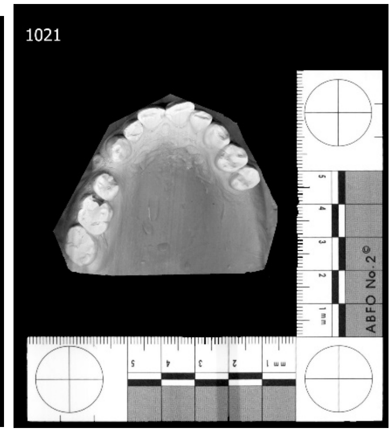
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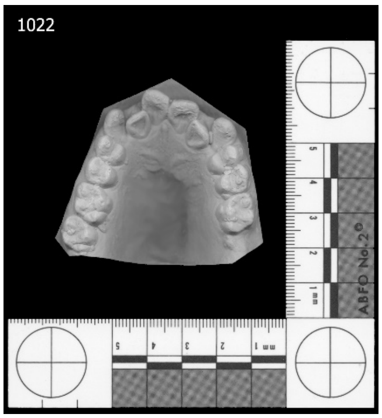
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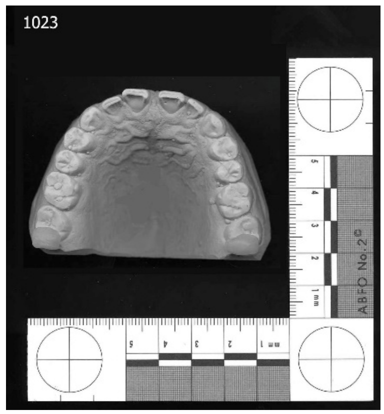
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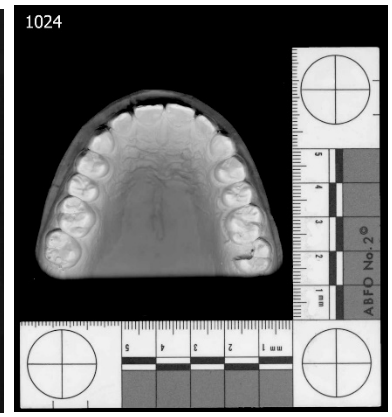
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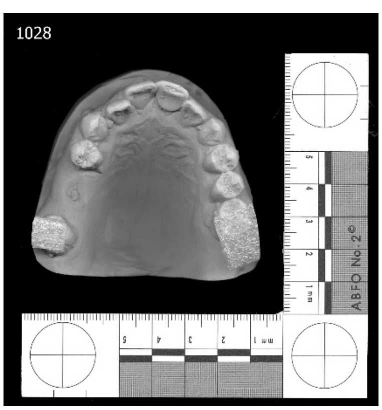
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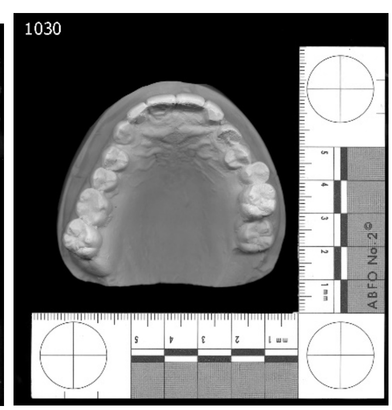
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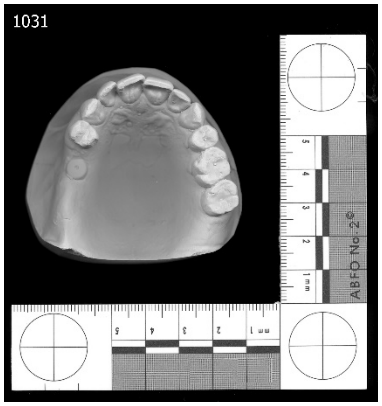
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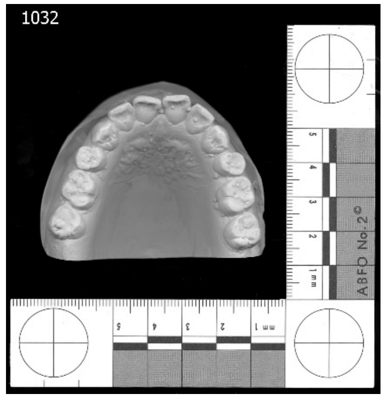
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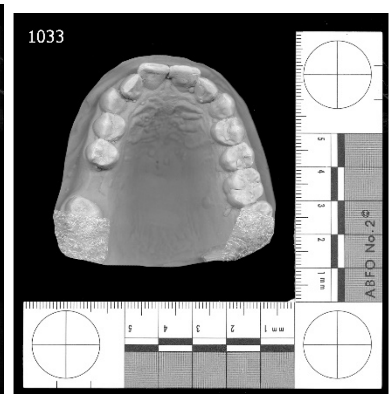
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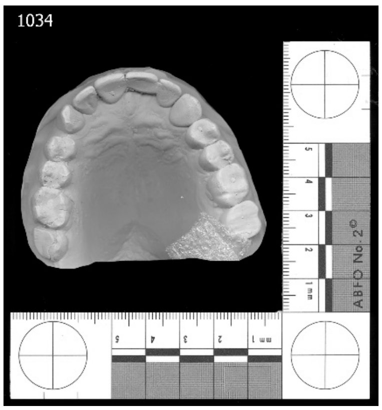
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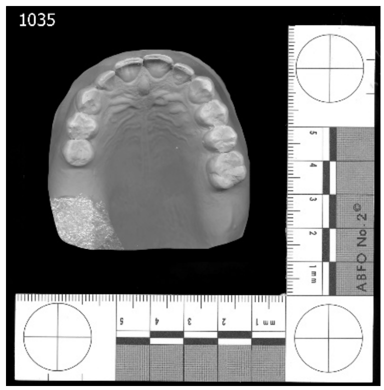
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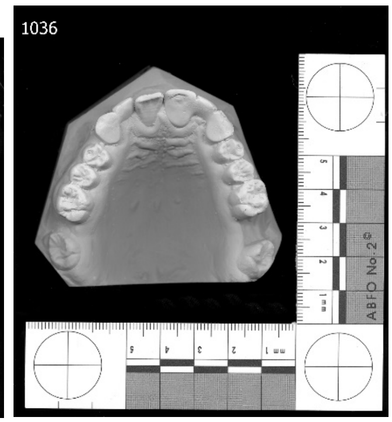
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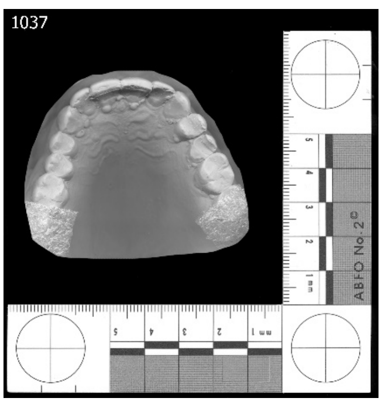
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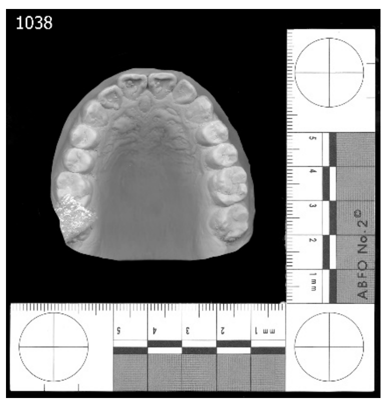
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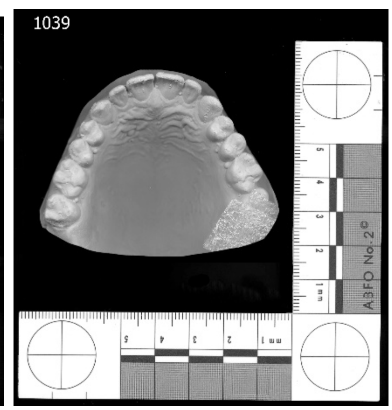
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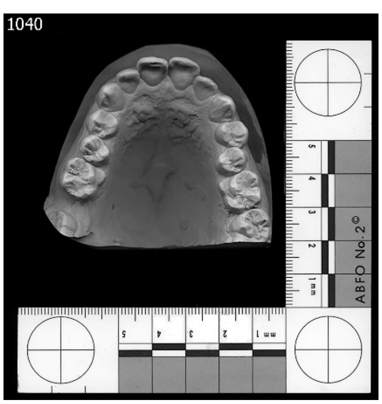
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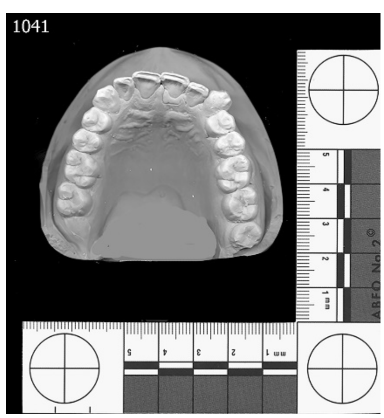
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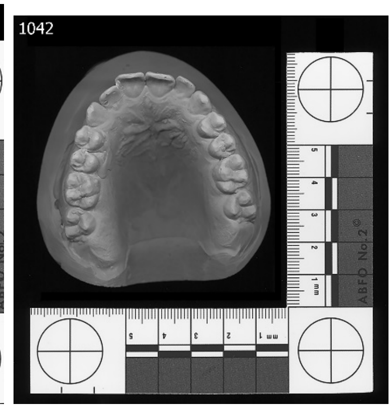
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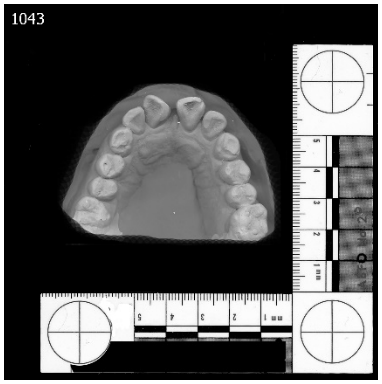
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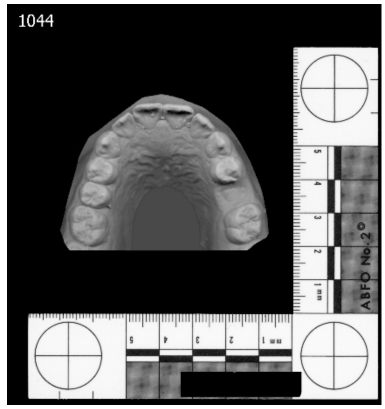
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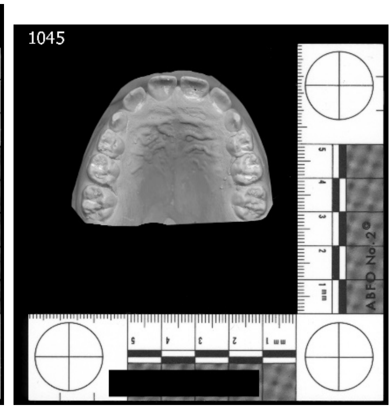
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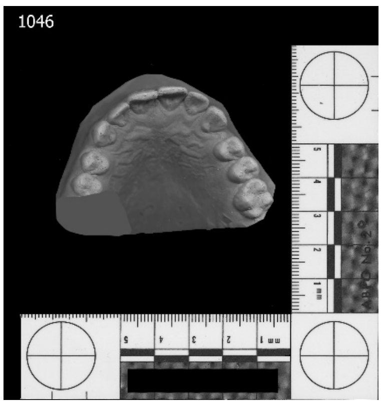
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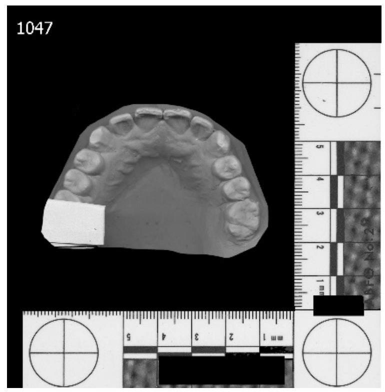
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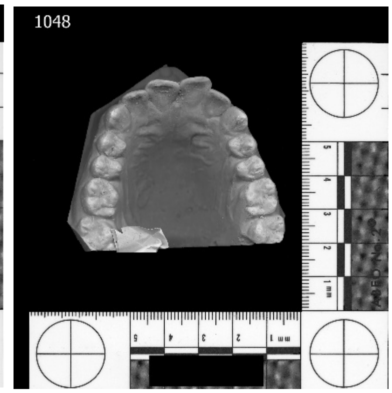
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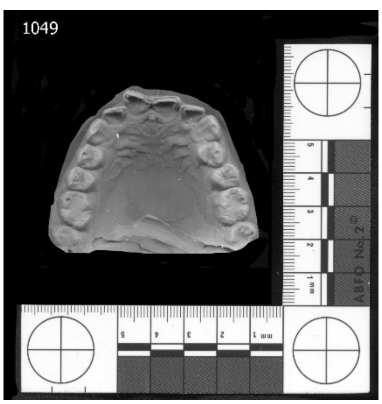
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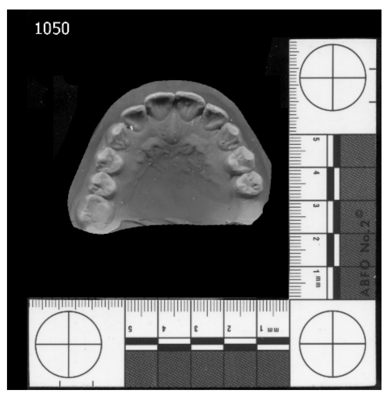
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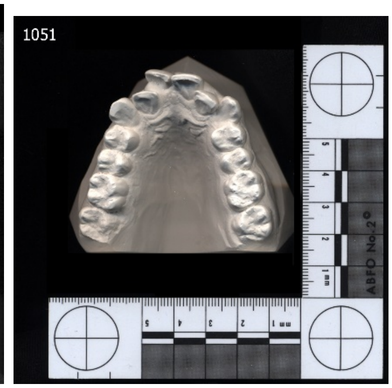
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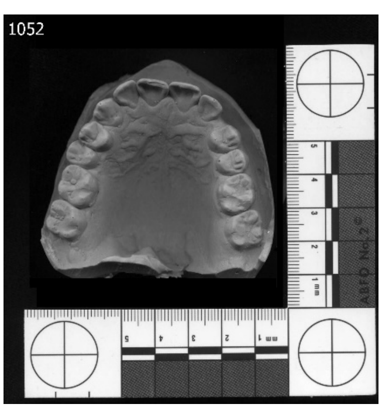
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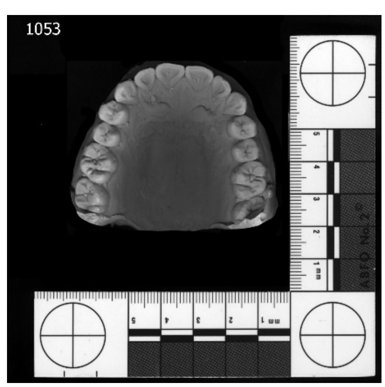
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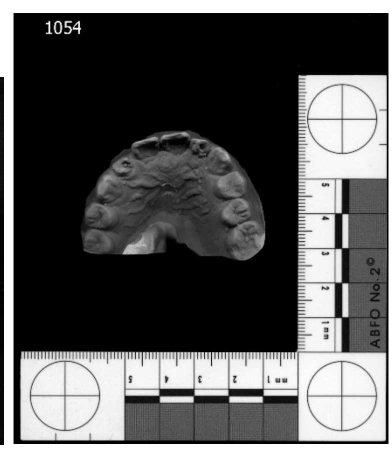
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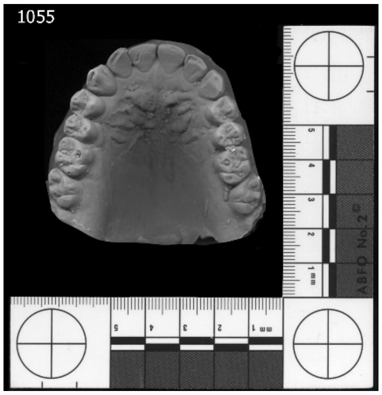
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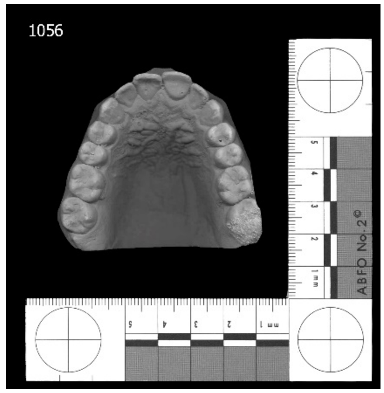
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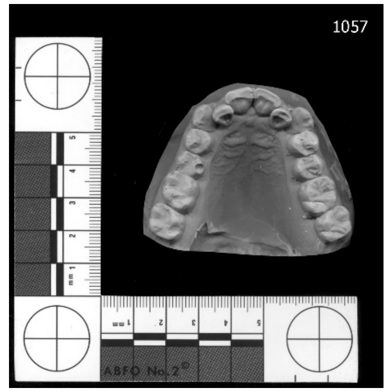
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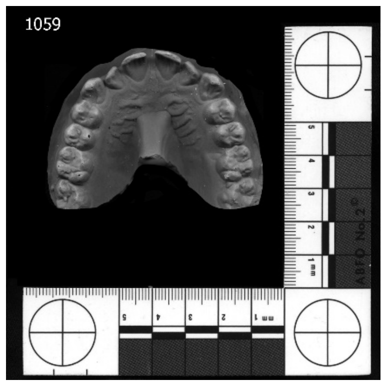
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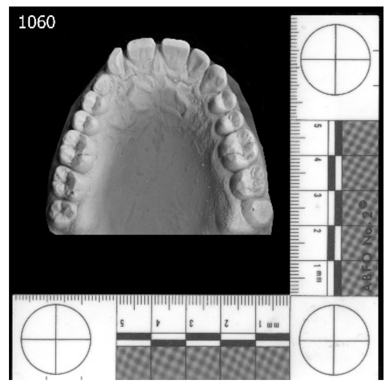
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