Design and Development of a Palatal Rugae based Biometric Identification System

By

Essa A. Assiri

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Department of Biomedical Informatics

School of health Related Professions

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By:

Essa A. Assiri

Dissertation Committee:

Dr. Syed Haque, PhD, PhD

Dr. Shankar Srinivisan, PhD

Dr. Frederick Coffman, PhD

Approved by the Dissertation Committee:

____________________________________ Date ______________

____________________________________ Date ______________

____________________________________ Date ______________

____________________________________ Date ______________

Abstract

Background: In the field of forensic odontology, palatal rugae plays a promising role in extracting identifications. The advantage of using 3D images of the palatal rugae is the accurate measurement results. Furthermore, the multi-shapes abstraction of the palatal rugae makes it easier to handle and analyze for the purpose of auto-shape-detection in the future. In doing so all the currently recognized criteria of biometrics science will be fulfilled in order to consider the palatal rugae recognition as one of the novel biometric technology.

Objectives: To investigate the unique features of the palatal rugae's shapes and measurements and use it to establishing a landmark for extracting biometrics based identification.

Design: An intra-oral scan images used to get a 3D model replica of the upper jaw to come up with a set of biometrical features for use in classification and detection.

Methods: The study consists of 24 subjects, 12 males and 12 females, which are used to validate the workflow of the biometrics based identification extraction model by using only one palatal rugae; The first right palatal rugae (FRPR). The identification sequence is a result of the concatenation of both shape and measurements for the FRPR.

Results: Palatal Rugae Identification Extraction Model (PRIEM) facilitated by two main inputs. Shape analysis and measurement analysis. The shape analysis investigates the incisive papilla as a landmark as will as a classification for the palatal rugae shapes. Moreover, the first right palatal rugae is conducted to be the only one used to extract the identification rather than going through the whole palate. The measurement analysis conducted the middle point of the incisive papilla to use it as a landmark position for other measurements. A zero matches were found in this study indicating that the FRPR pattern is unique and applicable to use as a biometrics based identification.

Conclusion: The study estimated the uniqueness of the FRPR pattern by three ways: uniqueness of PR as a biometrics based identification, the uniqueness of FRPR-shape pattern, and the accuracy of palatal pattern measurement in 3D. The use of FRPR is simplify the way of extracting the palatal rugae identification.

*Key words**: Biometrics based identification; Palatal rugae; Forensic odontology.***

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Chapter 1: INTRODUCTION

1.1 Introduction

Human identification is one of the most studied topics in the forensic science because it interacts directly with the human remains to establish identity of those who are not identified [1]. It's often difficult to establish the human identity in forensic identification. DNA, fingerprints, dental records, and iris imaging are the most used methods to get human identification [2]. In the field of forensic odontology, oral cavity and teeth prints plays a very effective role of the uniqueness of the teeth. However, the loss of the teeth due any trauma or any dental treatment plan makes these kind of identification not valid [1,2,4,5].

Therefore, the answer to the questions like ‘‘Who are you?’’ and ‘‘Are you who you claim to be?’’ are basically answered by the use of Biometrics-based identification. The biological measurements about an individual is usually used to personalize identification, regardless of method, is ubiquitous in our daily lives [31]. To identify an individual based on biometrics data in a unique approach, the following characteristics of biometrics data are desirable: (1) highly unique to each individual, (2) easily obtainable, (3) time-invariant (no significant changes over a period of time), (4) easily transmittable, (5) able to be acquired as non-intrusively as possible, and (6) unique in shape by humans without much special training. The last characteristic above is helpful to manual intervention, when deemed necessary, after an automated biometrics-based identification verification system made a decision [32].

Researchers from another hand have been always fascinated about the irregular elevations of the mucosa areas that located in the anterior upper palate. Those series of transverse ridges on the interior part of the palate in both sides are called palatal rugae. Palatal rugae form a pattern that considered unique to an individual like fingerprints.

Sassouni V had written about the uniqueness of this particular part. He described it as “palatoprint” early in 1957. he mentioned that no two palates are alike in their shape and the palatoprint, as he described, does not change during the person’s growth [30]. Once the palatal rugae formed, the length is the only parameter that changes during the human growth. Ritter, from another hand, studied the rugae of twins and found that the pattern of the palatal rugae is similar but not identical [2].

The palatal rugae are protected from accidents or environmental traumas. Also, similar to fingerprints, palatal rugae even reappear after traumatic or surgical intervention. Unlike fingerprints and the iris imaging due to their exposure to surrounding environment, palatal rugae position in the head makes it more protected by other facial parts like cheek, muscles, teeth, lips, and bones. It is because of the stability, postmortem resistance, uniqueness, and the low utilization cost, palatal rugae plays a potential forensic identification parameter. Moreover, palatal rugae pattern could be used as a parameter to recognize population ethnicity as well.

Despite the reliability, simplicity, and the economic advantage; a computerized forensic rugoscopy is not used in Saudi Arabia. The need of having a computerized standardization is obvious with the reasons that have been mentioned above. Hence, the present study aims to test and validate a new methodology of taking and storing those patterns using a 3D scanner that create a 3D prints of the patient's upper jaw. All scanning procedures takes its place in King Khalid University, Collage of Dentistry, Abha, Saudi Arabia.

Those 3D objects are translated into qualitative and quantitative parameters that could be used to determine the differentiation of palatal rugae numbers and shapes among males and females in Saudi Arabia. Due to the lack of complete standardization in interpretation, this study is compares the most significant differentiation in shape and numbers between male and female to determine standardization in the field of forensic odontology.

Moreover, as a result of having those data stored in one place, ethnical differentiation will appears as well comparing with the other databases that have been published already in India, South Africa, Japan, and Europa. Thus, this study will show if there is a major specification with the Saudi rugae compared with the other ethnicities.

1.2 Background of the Problem

Previous studies were concentrated to investigate differences in the shape of the individual palatal rugae in two or more populations. Most importantly, all previous studies' methodologies were doing the comparison using a stone cast. There are number of disadvantages using such a technique to complete the process of palatal rugae identification.

The disadvantage of using stone casts includes; risk of breakage of damage, the difficulties of physical storage, their heavy weight, and burden in sharing their data with other related or governmental professionals who involves directly to the patient's health care or identification data. Moreover, the time consumption, quality of the replica, and specific measuring are other reason behind doing such a study [28, 29].

The advantages of having 3D models of the palatal rugae includes; the accuracy and precision of the 3D oral scanners that have been used in this study, 3D objects include meta data about the palatal rugae coordinates within all exported files with extension ". stl" which is stands for "Stereolithography". Hence, all numeric information could be extruded from such row file. Moreover, stone cast could be recreated by using 3D printing technologies. It could be available when it needed for the sake of accuracy and storage.

1.3 Statement of the Problem

Personal identification plays a critical role in our society, in which questions related to identity of an individual such as "Is this the person who he or she claims to be?" is asked so many times every incident where the body is unidentified is a regular bases by hundreds of thousands of organizations in forensic associations, health care, government, and etc. With the rapid evolution of information technology, people are becoming even more and more electronically connected. As a result, the ability to achieve highly accurate automatic personal identification is becoming more critical. However, almost all types of biometrics are exposed to the outside environment, where is it more likely to get damage and altered during traumas like drowning and fire. palatal rugae position in the head makes it more protected by other facial parts like cheek, muscles, teeth, lips, and bones. It is because of the stability, postmortem resistance, uniqueness, and the low utilization cost, palatal rugae plays a potential forensic identification parameter. Researchers have been always extracted a lot of information about both the uniqueness and the characteristics of the palatal rugae during their work and methodologies. However, most of those researches are doing the study by using a manual measurements tools which are used to measure small distances in straight line with curved and wavy shapes. Thus, the accuracy and the flexibility of measuring such shapes would not be valid to be accepted as a biometrics tool in the enforcement law.

Hence, a systematic digitalized software approach is needed to determines the correct measurements of those parts to standardize and demonstrate the differences and similarities in the qualitative and quantitative parameters of palatal rugae. Moreover, the use of palatal rugae patterns will aid to specifies the Saudi Arabian ethnical characteristics and compare it with the other ethnicities to see if this population have uniqueness of the overall shape or not.

1.4 Significance of Palatal Rugae Biometrics

In the field of rugoscopy, it is well known that the palatal rugae pattern is as unique as the fingerprints and it retains its shape from the third month in the embryo phase until death. The anatomical position of the palatal rugae makes it more protected by other facial parts like cheek, muscles, teeth, lips, and bones. It is because of the stability, postmortem resistance, uniqueness, and the low utilization cost, palatal rugae plays a potential forensic identification parameter. Moreover, the bone and teeth keeps the rugae pattern protected from trauma and high temperatures. Thus they can by reliable as a reference landmark in the field of forensic odontology [2,4,5]. Moreover, In recent years there have been localized natural disasters and terrorist acts which have highlighted forensic odontology within forensic science, police departments and the wider community to obtain the personal identity for those who lost in such disasters.

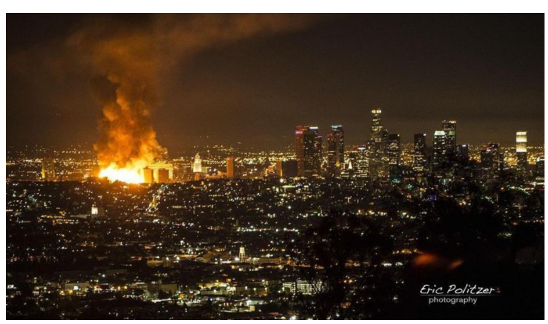


Figure 1 Fire in Los Angeles, California USA By Eric Politzer, Dec 8, 2014

Figure 2 China's Sichuan province on May 15, 2008.

Figure 3 Japan Tsunami 2011: Wave Swallows the Land

1.5 Purpose of the Study

Investigators have been always suggested that palatal rugae are unique to each individual like fingerprints [1, 2, 5, and 10]. However, these researchers have disagreed as to whether or not legal measurement tools could be applied on palatal rugae since the shape of the palatal rugae pattern is complicated and have curved and twisted shapes. Previous studies used poor duplicating materials and may not have considered the effects of using new technologies such as the 3D geometric morphometric. The oblivious use of other features of tools, such as 3D objects, computerized measurements, filing system, database for the Saudi population palatal rugae, or some combination of these, to aid in the identification, may have influenced their results. The purpose of this investigation was to determine if palatal rugae can be measured in a new way in order to extract features that might been hidden from previous investigators.

1.6 Aims and Objectives

In the field of Biometrics-Based identification, classifications and methodologies are quite deferent from one researcher to the other. Moreover, in the field of rugoscopy, the main concentration was about the statistical outcomes that investigators got from the number of the rugae that investigated in one group and compare it and another group. However, The main idea behind doing this study is to create a new way of measuring the biometrical characteristics of the palatal rugae by using the modern technologies that are exists already in the field of dentistry such as the intra-oral scan to get a 3D model replica of the upper jaw as well as supporting the incomes with algorithms and functions from the field of computer science that could comes with better and more accurate results as an outcomes in action for the field of the forensic odontology. Thus, all criteria of biometrics will be fulfilled in order to conceder the palatal rugae recognition as one of the biometrics technologies.

1.6.1 Aims

The aim of this study is to examine the biometrics based characteristics for the palatal rugae patterns of Saudi adult population sample and use it as a biometrics based identification by using a (3D) three dimensional replica of the upper jaw of the participants. Moreover, to evaluate the quality of inserting and retrieving that information by translating the three dimensional coordinates into a numeric output that will be reuse to represent the patient's identification for the sake of using it as a new way to do the filing system in King Khalid University, Abha, Saudi Arabia.

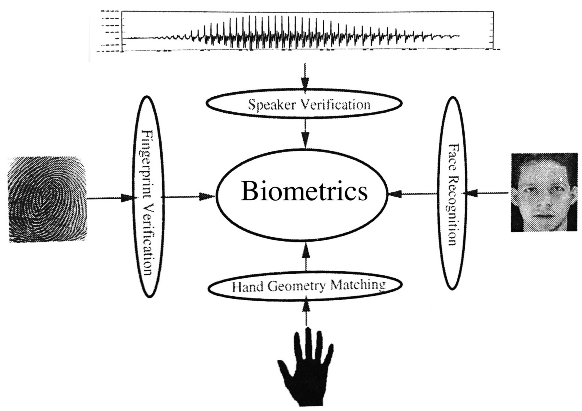


Figure 4 Biometrics Based Identification Multimodal

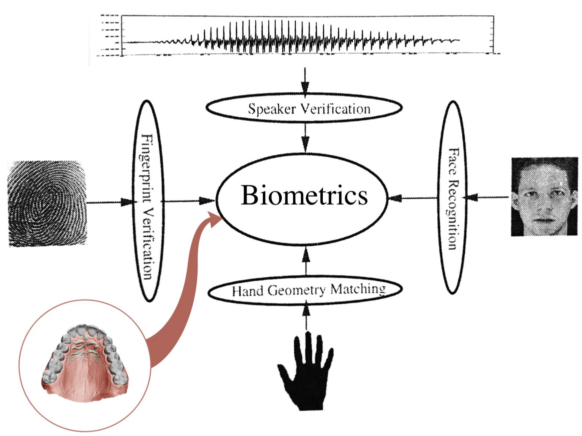


Figure 5 Adding the Palatal Rugae to the Biometrics Based Identification Multimodal

1.6.2 Objectives

- To study the biometrics characteristics of the palatal rugae.

- To study the morphology of the palatal rugae by using three dimensional (3D) software in a sample of Saudi's population for identification purposes.

- To determine if there is a gender differentiation in the palatal rugae patterns in Saudi's population.

- To compare the ethnicity of the findings with the results published in other literatures.

1.6.3 Hypothesis

- There is an approach to use the palatal rugae as an identification based biometrics.
- There is a new methodology of establishing an identification based matrices for the subjects based on the palatal rugae based on measurement.
- There is a new methodology of establishing an identification based matrices for the subjects based on the palatal rugae based on shape.
- There is a unique pattern for each subject that could be used as an identification based biometrics.
- There are measurement differences in the palatal rugae pattern between the 3D model and the stone cast.

- There is a possibility to use the first right rugae to establish an identification without the need of the rest of the rugae.

- There are 3D shape differences in the palatal rugae pattern among Saudi population.
- There are 3D size differences in the palatal rugae pattern among Saudi population.
- There are biometrical characteristics that allows the palatal rugae to be a promising tool in forensic odontology.

Chapter 2: LITERATURE REVIEW

2.1 Biometrics Based Identification

Biometrics refers to metrics related to human characteristics. Biometrics authentication (or realistic authentication) is used in computer science as a form of identification and access control. It is also used to identify individuals in groups that are under surveillance. The use of biometrics based identification supported the field of forensic science to get more accurate results about any crime related behavior. Therefore the outcomes of the biometrics added so much for the forensic world [52,53,55].

Biometrics Criteria:

What biological measurements qualify to be a biometric? This question is answered by R. Clarke in 1994; where the following seven elements are critical in order to conceder a technique as a biometric measurement or not [32, 58]:

- **Uniqueness**.

  No two persons should be the same in term of the characteristics

- **Universality**.

  Every person should have the characteristics.

- **Permanence**.

  Characteristic should be invariant with time.

- **Collectability**.

  Characteristic can be measured quantitatively.

- **Performance**.

  The achievable identification accuracy.

- **Acceptability**.

  To what extent people are willing to accept the biometric system.

- **Circumvention**.

  How easy it is to fool the system by fraudulent technique.

2.1.1 Significance of Biometrics-Based Identification

Day by day, biometric identification is getting more important. Different techniques have been developed, each of them having its own advantages and disadvantages, according to user acceptance, cost, and performance [30].

A biometric system is essentially a pattern recognition system that makes a personal identification by establishing the authenticity of a specific physiological or behavioral characteristic possessed by the user. Logically, a biometric system can be divided into the enrollment module and the identification module. During the enrollment phase, the biometric characteristic of an individual is first scanned by a biometric sensor to acquire a digital representation of the characteristic. In order to facilitate matching and to reduce the storage requirements, the digital representation is further processed by a feature extractor to generate a compact but expressive representation, called a "template." Depending on the application, the template may be stored in the central database of the biometric system or be recorded on a magnetic card or smart-card issued to the individual. The biometrics promise is to make authentication simpler and the personal information or any important data in a higher level of security.

2.1.2 Physiological and Behavioral Characteristics

Biometrics-based identifiers special measurable characteristics used to describe biological parts of individuals [38]. They are often describing the physiological and behavioral characteristics [39]. The physiological properties are actually related to the shape of the dedicated part of human body, such as finger, hand, face, and palatal rugae, where a big sector of the forensic science is labeling them with scientific names such as: fingerprints, face recognition, palm veins, DNA identification, palm prints hand geometry, palatal rugoscopy, and iris or retina recognition. From another hand, the behavioral characteristics can be categorized as a pattern of behavior of a person that could be measured as well by the use of biometrics-based identifiers. Behavioral properties are including the type of rhythm, gait, and voice. Some investigators have coins the term "Behaviometrics" to describe the letter class of biometrics.

2.1.3 DNA

The word DNA is actually the initials stand for "Deoxyribonucleic Acid", found in the cells of biological being, including the human body. The DNA is a very long molecule and is found in the nucleus of cells. Although each person's

DNA is unique (unless he/she has an identical twin), the techniques for identification only look at small parts of the DNA. It is important to realize that a person will usually have the same DNA throughout their body in every cell with a nucleus. That is, the same DNA profiling results for one person will be obtained whether testing blood or semen or muscle tissue [33].

The use of the DNA profiling includes the following in the field of forensic studies: A murder where it appeared that a struggle took place and blood from the murderer was left at the scene. This would be compared to a sample of blood from the suspect. Another usage of the DNA profiling is occurring when a murder where a blunt instrument was used and a suspect was found with a club on which there were dried blood stains. The blood on the club would be compared to the victim's blood. Also in the incidents of a rape case where seminal fluid from the offender can be taken from the victim. This would be compared to a sample of blood from a suspect.

The story of the use of DNA in the field of forensic science took its place in Leicestershire, England. Where two young girls; Lynda Mann and Dawn Ashworth, were sexually assaulted and murdered in 1983 and 1986[33]. The police had suspected that the same person had committed both crimes. The strange thing about this story was a local man confessed that he was the person behind killing one of those girls and the blood of the girl was compared to the suspected semen recovered from the crime scenes. The result of the laboratory did not match the semen in the crime scene with the confessed man. Therefore, the need for an alternative method was obvious. The first use of DNA testing from all adult men in three local villages was conducted in after the failure of other methods. The police tested over 4000 men without a match. However, about a year later, a woman at a bar heard a man who was talking about fooling the investigation by giving his blood sample to a friend named Colin Pitchfork. The police interviewed Mr. Pitchfork, collected a blood sample from him, and found that his DNA profile matched sperms that found in the crime scene for both murder. He was thereafter convicted and sentenced to life in prison. The story behind the first application of forensic DNA typing or “generic fingerprinting”, as it was the called, has been well told in Joseph Wambaugh’s the Blooding [33].

With the huge progress of the computer technology, DNA methods have been rapidly used in the field of forensic science, or forensic DNA analysis. In the mid-1980s, the use of computers at home and workplaces has been increase dramatically. The computers production get larger and the products get faster and more powerful every year. Moreover, the impact of this revolution did not stop there; the amazing idea of the Internet, which has a very large impact of the humanity in general and daily lives in specific, was the reason behind having shareable information around the globe. The knowledge of DNA is no different story. In 1985, the multi-locus RFLP (Restriction Fragment Length Polymorphism) probes were first reported. At that time, the average computer operating speed was less than 25 MHz Almost 30 years later in 2015, computing speed have reached the processing speed of 3.5 GHz [34, 38].

Table 1 The Development of DNA biotechnology since 1985.

Year	Development in DNA Biotechnology
1985	PCR process first described
1986	Automated DNA sequencing with 4-colors first described
1989	DNA detection by gel silver-testing, slot blot, and reverse dot blots first described
1992	Capillary arrays first described
1993	First STR results with CE
1994	Hitachi FMBIO and Molecular Dynamics gel scanners; first DNA results on microchip CE.
1995	ABI 310 Genetic Analyzer and TaqGold DNA polymerase introduce
1996	STR results with MALDI-TOF and GeneChip mtDNA results demonstrated.
1998	2000 SNP hybridization chip described
1999	ABI 3700 96-capillary array for high-throughput DNA analysis; chromosome 22 fully sequenced
2000	First copy of human genome completed
2001	ABI 3100 Genetic Analyzer introduced
2003	Human Genome Project completed with the 'final' sequence coinciding with 50th anniversary of Watson-Crick DNA discovery.

Our DNA molecules are the same between people. Almost 99.7% similarity. Only a small fraction of our DNA, which is about 0.3% or ~ 10 million nucleotides, differs between all human. In that particular part of the fraction. The DNA identification took its place to differentiate between people and the other. These variable regions of DNA provide the capability of using DNA information for human identity purposes. Methods have been developed to locate and characterize this genetic variation at specific sites in the human genome.

There are three methods are currently used to analyze the DNA findings. All of these methods are reliable. However, there are some lack of obtaining the results or inconclusive if the quantity of the sampling was insufficient to analyze the gathered DNA evidence. The sophistication of the technology used in analyzing the DNA is increasing and in its ability to differentiate individuals [33, 34].

The most common form of DNA analysis is called: Polymerase Chain Reaction (PCR)[34]. There are three methods are currently used to analyze the DNA findings. All of these methods are reliable. However, there are some lacks of obtaining the results or inconclusive if the quantity of the sampling was insufficient to analyze the gathered DNA evidence. The sophistication of the technology used in analyzing the DNA is increasing and in its ability to differentiate individuals.

The most common form of DNA analysis is called: Polymerase Chain Reaction (PCR)[34]. The PCR testing development has greatly advanced the field of forensic science by increasing the chance of having a success rate of the analysis of fraction of a sample, aged, degraded, or very small biological evidentiary samples. PCR testing allowing the investigators to study and analyze evidence samples that previously could not be tested because the quality or the amount of fraction of sampling that material collected from a crime scene that older testing failed to do so [35].

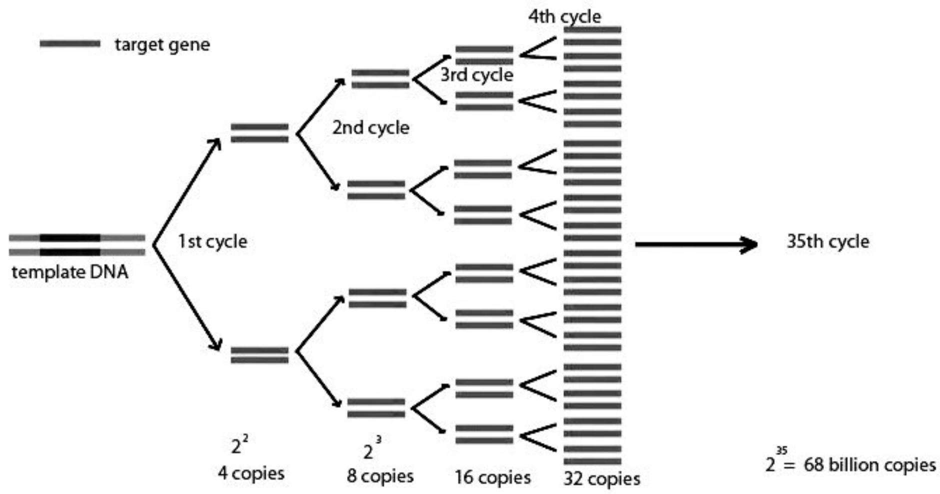


Figure 6 PCR Amplification method.

The idea behind such a test is simply by taking a very small amount of DNA from biological evidence and making a rapid repetition of that sample till get millions of copies of it. This process often referred to as PCR amplification. Therefore, creating enough DNA to allow laboratory technicians to analyze degraded biological material [34]. An example of using such method in the United States, is the CODIS database, where a group of 13 different locations are used for this kind of analysis and making an evidence samples and to generate DNA profiles from convicted offenders [36].

An extreme care must be exercised to prevent contamination when identifying, collecting, and preserving because of the capability of PCR testing to amplify very small quantity of DNA. Thus, researchers and investigators in the laboratories or people who work there should always avoid touching other evidence, use clean instruments, wear disposable gloves, when handling the evidence [37].

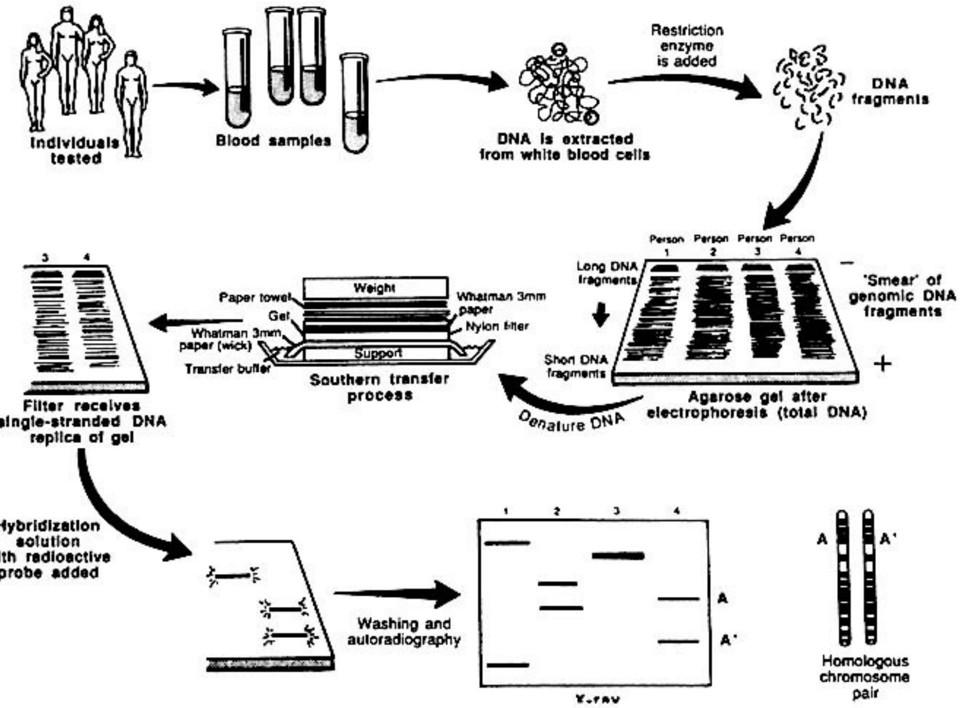


Figure 7RFLP method for extracting DNA identification

"Schematic representation of Southern blotting of single-locus, multi-allelic VNTR. In example shown here, DNA from four persons is tested. All have different patterns. Three are heterozygous and one homozygous, for a total of seven different alleles. From L. T. Kirby, "DNA Fingerprinting: An Introduction," Stockton Press. New York, 1990. Copyright © 1990 by Stockton Press. Reprinted with permission of W.H. Freeman and Company." [37]

Another method used to analyze DNA evidences is: Restriction Fragment Length Polymorphism (RFLP) testing. RFLP testing usually requires a sample that has 100,000 or more cells and contains DNA that is not degraded or broken into smaller fragments. Eventually, a restriction enzyme added to the samples to be compared. The enzyme cuts the DNA into smaller fragments [37]. The DNA fragments are placed onto a electrophoresis gel [43]. When the electric current is applied to the gel, the DNA fragments migrate through the gel toward the positively charged poll. The smaller the fragment; the faster it will migrate. After a set of time, researchers identify fragments of different lengths by staining the gel or by specifically highlighting fragments that contains tandem repeats [36, 39].

Another type of DNA testing is: PCR testing on DNA from the mitochondria of the cell. Which is conducting where samples that are unsuitable for RFLP or PCR nuclear DNA testing, such as dried bones or tweet, hair, or samples that contains very little or highly degraded nuclear DNA, takes it place in this type of testing. The mitochondria DNA testing is not reachable all the time, it available only in limited number of laboratories primarily because of time it takes to perform the tests. Therefore, the usage of the first two : PCR and RFLP are much more useful in the field of forensic science in order to fulfill one important element to make it a valid biometric identification tool; which is the availability. more details about the main characteristics between RFLP analysis and PCR analysis.

GENBANK: A DATABASE OF DNA SEQUENCES

Genetic variation from DNA sequence information around the world is cataloged in a large computer database that eventually got the name from the genome as GenBank. As John M. Butler mentioned in his book "*Forensic DNA*

Typing: Biology, Technology, and Genetics of STR Markers"; this kind of databases is maintained by the National Center for Biotechnology Information (NCBI), which is a part of the National Library of Medicine with the U.S. National Institute of Health. The NCBI was established in 1988 as a national resource for molecular biology information to improve understanding of molecular processes affecting human health and disease. As of December 2003, GenBank contained over 36 billion nucleotide bases from more than 30 million different records[41].

The GenBank database is designed to provide and encourage access within the scientific community to the most up to date and comprehensive DNA sequence information. Therefore, NCBI places no restrictions on the use or distribution of the GenBank data. However, some submitters may claim patent, copyright, or other intellectual property rights in all or a portion of the data they have submitted. NCBI is not in a position to assess the validity of such claims, and therefore cannot provide comment or unrestricted permission concerning the use, copying, or distribution of the information contained in GenBank [42].

According to the National Center for Biotechnology Information, the U.S. National Library of Medicine "There are several ways to search and retrieve data from GenBank.

- Search GenBank for sequence identifiers and annotations with Entrez Nucleotide, which is divided into three divisions: CoreNucleotide (the main collection), dbEST (Expressed Sequence Tags), and dbGSS (Genome Survey Sequences).

- Search and align GenBank sequences to a query sequence using BLAST (Basic Local Alignment Search Tool). BLAST searches CoreNucleotide, dbEST, and dbGSS independently; see BLAST info for more information about the numerous BLAST databases.
- Search, link, and download sequences programmatically using NCBI e-utilities."[42]

The Biometrics based Identification will have no benefits what so ever from collection information and samples from people without storing them in a database that would use for the sake of comparison and matching. That's why the idea of saving all of these data and dataset is essential for get the most of the biometrics based identification and connect the usability of it with deferent part of the legal department in any government. Not only in the field of DNA identification, but also in all kind of physiological and behavioral biometrics based identification inputs such as fingerprints, iris recognition, and palatal rugae.

METHODS FOR MEASURING DNA VARIATION

One problem that is always facing the field of forensic DNA laboratories is the portability part of this technique [32]. DNA tests need a lot of equipment and tools in order to make a single decision about person identification. Despise the time consumption that measured between 2 days to three weeks. However, techniques used by forensic DNA laboratories for human identity testing are based on the same ideas and methodologies that been used for the principles of the medical diagnosis and gene mapping for other purposes than DNA identification. The variety of sampling in this technique is amazing. From a blood sample to a part of hair could be successfully tested. The DNA is presenting in all of these forms such as; hair, bone, saliva, semen, and blood stains or any other biological part of the human body and remains. The reason behind that is the amazing division that happened in the whom. All cells are descending by successive divisions from a single fertilized egg. Therefore, the same print will be carried along within the human cells from the first day of he or she started until death. Moreover, the remains of the dead cells will still have the negative print of the living once; which is usable to identify persons as well. The DNA material is identical between any cell collected from any living creature and therefore provides the same forensic data that is crucial for identifying the origin [38].

As shown in the table below (table 2.2), which is cited from the author John M. Butler in his book: Forensic DNA Typing, Second Edition: Biology, Technology, and Genetics of STR Markers; he showed the primary approaches for performing the DNA test in the field of forensic DNA analysis which is classified into restriction fragment length polymorphism (RFLP) methods. From another hand, there is another set of techniques which calls: polymerase chain reaction (PCR) methods. All in all, have some advantages and some disadvantages. PCR-based technique has widely overtaken the RFLP methods. It is because of the performance that PCR is better with when we consider the quantity and the poor quality. PCR can handle forensic sampling in a better way that RFLP dose. Sampling methodology in the crime scene is getting low quantity as well as poor quality [41].

Table 2 The Characteristics of the most used methods in DNA analysis.

Characteristics	RFLP	PCR
Time required to obtain results	6-8 weeks with radioactive probes; around 1 week with chemiluminescent probes.	1 - 2 days
Amount of DNA needed	50 - 500 ng	0.1 - 1 ng
Condition of DNA needed	High molecular weight, intact DNA	May be highly degraded
Capable of handling sample mixtures	Yes (single-locus probes)	Yes
Allele identification	Binning required since a distribution of sizes are observed	Discrete alleles obtained
Form used in analysis	DNA must be double-stranded for restriction enzymes to work	DNA can be either single-stranded or double-stranded
Power of discrimination	~1 in 1 billion with 6 loci	~1 in 1 billion with 8-13 loci (requires more loci)
Automatable and capable of high volume sample processing	No	Yes

2.1.4 Fingerprints

fingerprints are one of the most studied biometric technologies used in the field of forensic science worldwide. the use of fingerprints as an identification had been played a huge role in the law enforcement almost a century so far. A wide usage of fingerprint application is applied for the sake of finding a convict during a crime scene investigation. Another usage of such applications is included within the process of personal authentication, an example of that is when you try to access a computer, get a passport, get a driver license, a get through a corporation network, or a home. So, there are some differentiations between the usage of fingerprint as an identification and as an authentication. The four basic approaches to identification based on fingerprint are widespread: First, the invariant properties of the gray scale profile of the fingerprint image or part of the mini scaled part of it to equalize the overall tone of it. Second, are the global ridge patterns. Third, are the ridge patterns of the fingerprints. Finally, the fingerprint minutiae; where the result of this approach is to get the ridges ending and bifurcation. It usage in the sake of authentication or identification are common in the crime scene and the criminal investigations, therefore, a major sector of each governments are supporting the evolution and the transformation of such technique in order to get a better recognition for the fingerprints.

From another hand, the use of fingerprint as a biometric is one of the oldest mode of personal identification. Moreover, it was the most widespread biometric tool in use today. However, the majority usage of the fingerprint covers the law enforcement part of the equation. The authentication era of the fingerprint still in growth but slower than the use of identification. The expectation is currently looking forward for a combination for factors that covers both identification and personal authentication side by side. These factors include, better hardware, faster processing, cheaper solutions, and smaller fingerprint capture devices to meet the needed application. An obvious reason behind looking toward such individuality is the rapid growth of the Internet services and transactions. This humongous growth raised the fear and the awareness to look for reliable and secure solutions. Thus, biometrics based identification is a reliable tool for such cases. It is important to understand that there are many different approaches and methodologies for using the fingerprints verification. Some of them are patents, others are in the scientific literature, and some may have kept secret from trading.

Matching the fingerprints can be classified into two main categories: identification and verification. The identification is simply the fingerprint matching for a certain incident happened in the past that the crime scene investigators are trying to see which print belong to which suspected. The unknown owner of the fingerprint is going through a process of matching it against a database of unknown fingerprints to associate the act with the identity. This type of matching called: one-to-many matching. From another hand, the verification matching is simply the comparison of a claimant fingerprint against an enrollee fingerprint. This type of matching called: one-to-one matching. the pattern of the fingerprint is stored in some compressed format and attached to the subject's other information like name and address or other identity. Therefore, such a process of authentication applies of persons' identification is denoted by one-to-one. Another kind of matching is used but not as widely as the other two is called the one-to-few matching. This kind of matching happened to serve a particular application needs. Where a fingerprint system is used by a few users, such as family members or users have a single field of interest to apply this kind of authentication to. The "few" here applies to the number between 5 to 20 used that this kind of application is accepting in order to have the access to that field of interest [46].

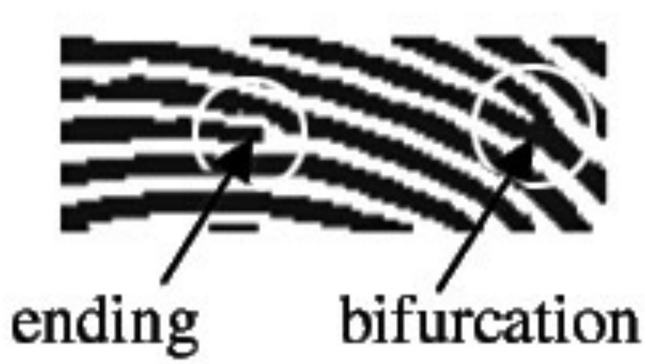


Figure 8 fingerprints minutiae: ending and bifurcation

The fascinating shape of the finger patterns that flows across the fingerprints called ridges. The spaces between those rides called valleys. Its the ridges that makes those fingerprints defines identity and therefore differentiates identifications applies from one to the other. Moreover, when we dive deeply inside those ridges we will finds an approach called minutiae matching. The two widely known minutia types are the endings and the bifurcations. The ending part of the ridge is where the terminates and the bifurcation part of the ridge is where the ridge splits from a single path into two other paths therefore it got the Y shape. The figure 1.3 is describes the two shapes of the fingerprints minutiae [45].

For more global matching, there is an approach to match fingerprints called global pattern matching or to simplify it “pattern matching”. In this matching approach, the flow of ridges is compared at all locations between a pair of fingerprint images. Therefore, a comparison will include the patterns of the overall print with the others. Three main types of fingerprints global pattern are there. Figure 1.4 is shown illustration shapes of those three types. Those types are: arch, loop, and whorl. Some investigators are using, during the matching, two more features related directly to the three categories. Core and delta are those features. The core can be thought of as the center of the fingerprint pattern. Form the other hand, the delta feature is a singular point from which three patterns deviate. The position of the core and the delta features can support the investigators to assume that those two features are land marking for the whole fingerprint pattern.

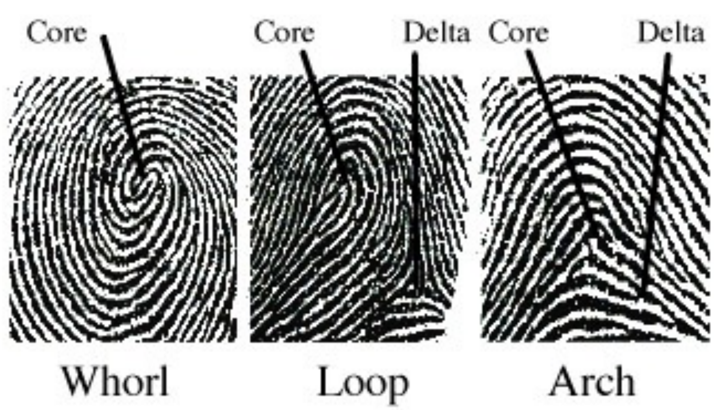


Figure 9 fingerprints patterns (bottom): Whorl, Loop, and Arch. Fingerprints landmarks (top): core and delta

There might be other features or patterns for the fingerprints, but here we are investigating the main criteria for understanding the critical differentiations between elements which majorly in use. Another criterion that investigators might put in mind is the size of the ridges and valleys for matching purposes; however, these type of criteria is changeable over time. Moreover, the position of a cut or a scar can be useful for matching a fingerprint. However, those kinds of damages are curable and artificially change during the time of investigation. Therefore, using such criteria is not a main aid for the investigation sake [43].

The problem with the fingerprints images is the noise that those images could produce. It is one of the noisiest image types. Fingerprints always found cut, dirty, creased, scarred, wet, etc. The purpose of having image enhancement steps is to clarify the definition of the ridges against valleys. Two main image processing process applies to enhance a fingerprint images: the adaptive, matched and the adaptive thresh holding. The redundancy of the parallel ridges is from another hand a useful criterion for matching the fingerprints [44]. A small area of the pattern can determine the matching filter. The filter of the redundant parallel ridges can be used to apply to every pixel in the image. In a technical terminology, this operation called spatial convolution. Another useful approach of having such a filter is to get rid of the false bridges that original noise image can produce. After the image enhanced and the noise reduced, the image is ready to illustrate the ridges. The major obstacle that paces the image enhancing for fingerprints is the difficulties of processing the binarization. The conversion process of image to black and white is listed in IBM website; and I imported the technique as is: "Image binarization converts an image of up to 256 gray levels to a black and white image. Frequently, binarization is used as a pre-processor before OCR. In fact, most OCR packages on the market work only on bi-level (black & white) images. The simplest way to use image binarization is to choose a threshold value, and classify all pixels with values above this threshold as white, and all other pixels as black. The problem then is how to select the correct threshold. In many cases, finding one threshold compatible to the entire image is very difficult, and in many cases even impossible" [47]. Therefore, adaptive image binarization is needed where an optimal threshold is chosen for each image area. Also, converting a deferent contrasted characteristic is vary from one fingerprint to the other, depending on the previous noises that my apply to the fingertips since the input could be deferent from more than one machine. Furthermore, contrast may vary from one section of the same image to the other, depending on the press of the fingertip at the cite [46]. Thus, a common image processing is used to scale up or down the volume of contrast and brightness as any image processing application. Another technique is to simplify the original images by dividing it into smaller boxes that control a smaller area for similar contrast; if needed more simplification added and smaller boxes divided until the whole pattern get the target homogeneous level of contrast. The final phase of processing the image enhancement is converting the 8-bit image that extracted from the fingerprint into an outlines that simplifies the overall shape of the pattern. This stage produces a thinned illustration for the whole fingerprint. Although all phases are consuming a lot of processing, it is forwarded to detect the desired results from the fingerprint. Endings are found at the termination lines of the binarization phase. Moreover, bifurcations are found at the delta area of three lines merging together.

All in all, fingerprints are one of the most studied biometric technologies used in the field of forensic science worldwide [45]. The four basic approaches to identification based on fingerprint are widespread: First, the invariant properties of the gray scale profile of the fingerprint image or part of the mini scaled part of it to equalize the overall tone of it. Second, is the global ridge patterns. Third, are the ridge patterns of the fingerprints. Finally, the fingerprint minutiae; where the result of this approach is to get the ridges ending and bifurcation. It usage in the sake of authentication or identification are common in the crime scene and the criminal investigations, therefore, a major sectors of each governments are supporting the evolution and the transformation of such technique in order to get a better recognition for the fingerprints [45].

2.1.5 Iris Imaging

The iris is the thin circular structure on the front surface of the human eye, the physiological responsibility of this part is to control the diameter and the size; therefore, control the amount of light that reaches the retina. The color of the eye is coming from the color of the iris, see Figure 10. In fact, the whole that allows light to come in (pupil) is open and close by stretching the iris in and out. In other words, the iris is the diaphragm that serves as the aperture to stop. Anatomically, the iris consists of two parts or layers. The first layer is the front pigmented fibro vascular known as a stroma and, the second layer is beneath the stroma, pigmented epithelial cells [49].

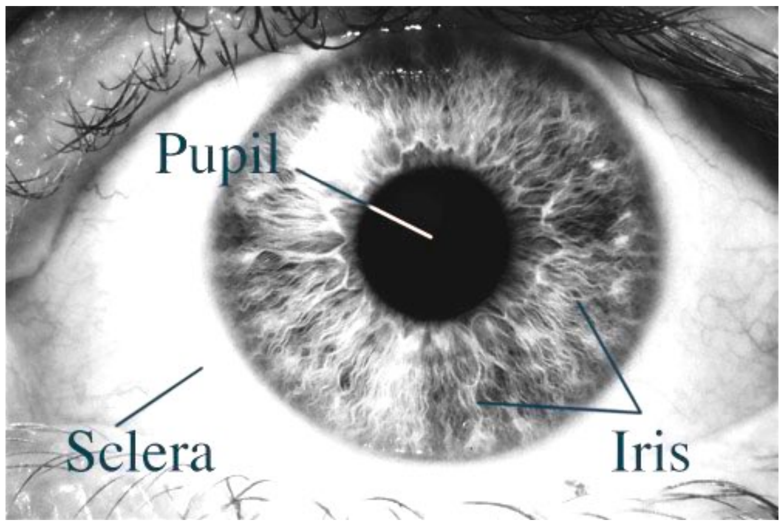


Figure 10 Simple anatomy for the position of the pupil and the iris

The visual texture for human determined at an early age during the embryonic development. Moreover, the place of iris considered to be unique for each individual in each eye [48].

Iris method of identification for matching and verification has gained acceptance in a number of areas. Where it started in a very selective area when the machinery equipment's needed were not affordable and the size was really hard to deal with especially when it's crucial to have time and space in mind. With the recent technologies breakthrough in size and price of iris technology, it allows for much greater implementation and consumption. These iris scanners, informally speaking, got a lot of acceptance and usage. Iris technology as a biometrics has been always fascinating when we talk about the accuracy. The reason behind the accuracy, is the rich details of iris pattern capturing technique. The imaging system in iris technology is resolving a minimum of 70 pixels in iris radius. Moreover, the conversion and upgrading resolves iris radius of 100 to 140 pixels has been more typical. To establish an iris identification, the system needs a camera, for example Monochrome CCD camera (480 x 640), with a band of 700nm to 900nm. Thais is required to make the imaging invisible to human. So, the system needs a wide angle lens for localizing the subject's eyes in focus. Also, the higher resolution imaging, the better iris details the system will have [48].

A lot of literatures have been discussing the accuracy and the promising measurements that iris biometrics could bring when it come to accuracy. Actually, a paper published by Seung-In Noh, *et al,* wrote about a new feature extraction method based on independent component analysis (ICA) for iris recognition, which is known as the most reliable biometric system. They extracted the iris features using a database of image filters which are selected from the ICA basis functions [50]. Seung-In Noh added, "The ICA basis functions themselves are sufficient to be used as filter kernels for extracting iris features because they are estimated by training iris signals. Using techniques of the ICA estimation, we generate many kinds of candidates ICA filters. To select the ICA filters for extracting salient features efficiently, we introduce the requirements of the ICA filter. Each ICA filter has a different filter size and a good discrimination power to identify iris pattern. Also, the correlation between bandwidths of the ICA filters is minimized. Experimental results show that the EER of proposed ICA filter bank is better than those of existing methods in both the Yonsei iris database and CASIA iris database", resource: Advances in Biometric Person Authentication, International Workshop on Biometric Recognition Systems, IWBRS2005 Beijing, China, October 22-23, 2005.[50] However, this is just one method of many can be found in the literatures. Here are some sample of other literatures for more reading about the topic of iris based biometrics: *An Iterative Algorithm for Fast Iris Detection* by Topi Maenpaa; *A Non-linear Normalization Model for Iris Recognition* by Xiaoyan Yuan and Pengfei Shi; *A New Feature Extraction Method Using the ICA Filters for Iris Recognition System* by Seung-In Noh, Kwanghyuk Bae, Kang Ryoung Park, and Jaihie Kim; *Iris Recognition Against Counterfeit Attack Using Gradient Based Fusion of Multi-spectral Images* by Jong Hyun Park and Moon Gi Kang; *An Iris Detection Method Based on Structure Information* by Jiali Cui, Tieniu Tan, Xinwen Hou, Yunhong Wang, and Zhuoshi Wei. [50]

There are some disadvantages using the iris based identification as a biometrics. The small targeted area, which is around one centimeter, to acquire from a distance around one meter. Also, the reflection surface of the eye can produce false data that located over the curve of the eye. Moreover, the physiological performance of the iris is moving the pattern open and close with deferent lighting scale. Therefore, changing the decoded part of the pattern which effecting the matching outcome. This kind of deformation is demanding extra environmental enhancements in order to standardize the amount of pupil expansion. Another issue related to the iris identification and verification is the way that eyelids are covering part of the iris; therefore, covering a part of the iris information that is usually used to identify the individuals [48, 49, and 50].

2.1.6 Ear

Many research studies have proposed the ear as a biometric. Researchers have suggested that the shape and appearance of the human ear is unique to each individual and relatively unchanging during the lifetime of an adult. There are several studies that address the question of uniqueness and classification of ears. No one can really prove the uniqueness of the ear, but two studies mentioned in [51, 52] provide empirical supporting evidence. In 1906, Imhofer found that only 4 characteristics were needed to distinguish a set of 500 ears [35]. The most prominent work is perhaps that done by Iannarelli (1989) [40].

Despite this potentially promising outlook, there are a number of limitations for the novel technology. For example, some experts question the ability of ears to serve as a practical identification tool because of the possibility of ear transformation with age. Although the ear is fully formed at birth, whether it significantly changes due to aging over time remains a controversial point. Yale Professor of Otolaryngology, Cellular and Molecular Physiology, and

Neurobiology Joseph Santos-Sacchi are also skeptical of using the ear as a biometrical indicator. “Additional measures [beyond fingerprints and facial recognition] for identification are always welcome, [but] people more likely will manipulate their ears with jewelry and so on, which can alter the shape of the ear. I do not know how effective it would be using the ears as a substitute for fingerprints, [though the] details of the outer ear are unique to people,” he says. Santos-Sacchi also adds that ears can be easily changed with plastic surgery. Other limitations that need to be addressed for image ray technology include hair and glasses frames covering the ears, insufficient lighting conditions, and varying angles of ear images.

Furthermore, some scientists doubt the need for this new technology. According to Dr. Gisella Caccone, Director of the DNA Analysis Facility on Science Hill at Yale, the use of ears as an indicator is not comparable to current technologies of biometric identification such as fingerprinting. “[Using the ears may be] faster and cheaper, but I do not know if it will be as accurate,” Caccone says. Fingerprint analysis has been the most common and reliable form of biometric analysis for the past century and has been implemented in many security packages. However, fingerprint biometric analysis technology, which analyzes the whorls, arches, ridges, and loops of fingerprints, has also been called into question and criticized despite its increased sophistication in recent years. Experts are concerned that fingerprints can be destroyed or worn away, which is actually common in certain work industries and in some types of accidents. And even irises, which also have been traditionally lauded as reliable biometric indicators, show evidence of reduced identification accuracy due to aging.

Since all identification techniques that are dependent on physical characteristics possess similar limitations, the advent of a promising new biometric technology is seen as a tool to supplement, not supplant, the use of current technologies. The image ray transform algorithm is therefore regarded skeptically but with hopeful interest. The use of ears as a biometric identification tool could potentially be very useful in surveillance situations when suspects are too far for an iris scan or when only profiles of suspects are attainable, such as in passport photos and in airport security ID checks. Additionally, establishing a database of ear images would be non-intrusive to individuals and cost-efficient to industries. Nixon's research group at the University of Southampton hopes to improve the algorithm so that it can eventually analyze three-dimensional images quickly enough to allow the program to translate from a merely fascinating technology with theoretical success to one that is applicable and practical in real-life situations, such as extracting information from blurry security camera photos.

2.1.7 Palatal Rugoscopy

Palatal rugae refers to the irregular elevations pattern of the mucosal ridges that take its place in the third part of the interior hard palate and it started the whole position behind the incisive papilla toward the inner part of the palate. Moreover, palatal rugae is parted in both sides by palatine raphe [1, 2, 3].

The palatal rugae are protected from trauma. Unlike fingerprints and the eye prints due to their exposure to surrounding environment, palatal rugae position in the head makes it more protected by other facial parts like cheek, muscles, teeth, lips, and bones. It is because of the stability, postmortem resistance, uniqueness, and the low utilization cost, palatal rugae plays a potential forensic identification parameter.

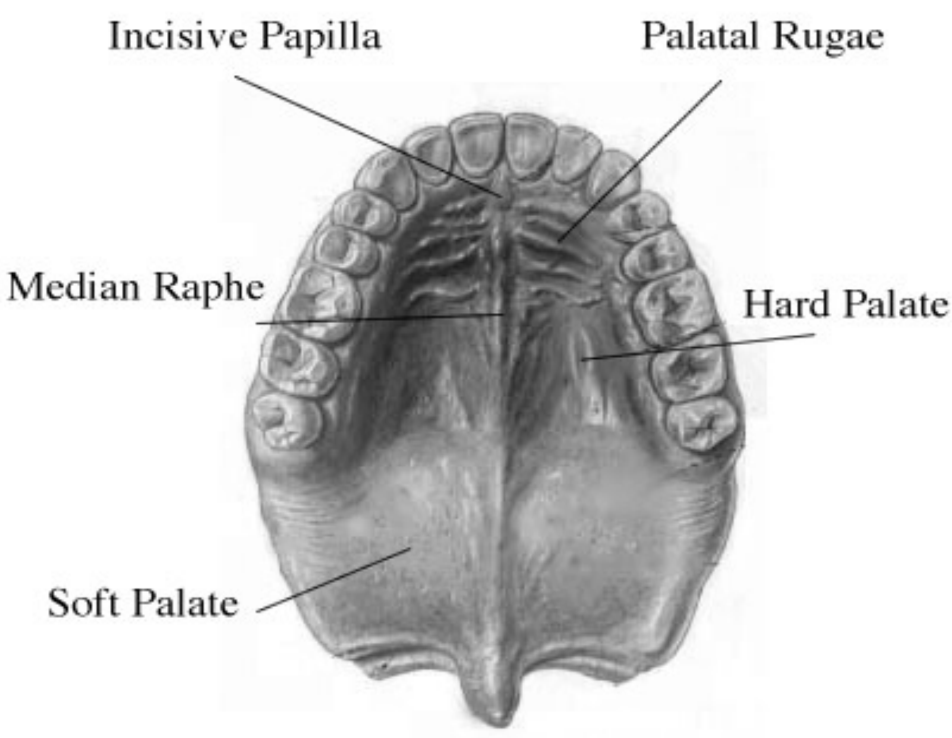


Figure 11 The main anatomical parts for the internal side of the upper jaw

Moreover, palatal rugae pattern could be used as a parameter to recognize population ethnicity as well. Figure 10 is describing the anatomical part of the palatal rugae in order to understand why such a part in the human body has such an importance in the field of forensic odontology for the purpose of human identification. The biometrics part of the palatal rugae pattern analyses can be done on a photographic image of the rugae area, dental cast or a 3D image of the rugae can do the job. In the literatures, dental cast of the rugae are marked using a HB lead pencil or black marker [10, 12, 20]. After outlining the primary rugae the cast is either scanned on a flat-bed scanner or directly observed with naked eye for analysis and calculation. Analysis can be carried out qualitatively and quantitatively values. Most of the literatures and previous investigators that done in the field of forensic odontology have utilized qualitative analysis of the palatal rugae. The most acceptable classification used was that of Thomas and Kotze (1983) modification of Lysell's classification (1955). Qualitative methods include; The qualitative characteristics of individual rugae mentioned below are a combination of classifications by Thomas and Koetze (1983), Hausser *et al* (1989) and Kapali *et al* (1997). Various characteristics of rugae are observed as point, straight, curved, wavy/sinuous, angled, unification, circular, converging, diverging, composed and non-specific. Quantitative methods, from another hand, are the total number of rugae are counted without considering the side of the palate [20,21]. To measure the length of the palatal rugae, investigators used a straight line measurements methodology to calculate the length between the origin and termination of each palatal rugae and groupes it into three categories main categories: *Primary* (where the straight length between the beginning and the end of the rugae is 5mm or more); *Secondary* (where the straight line measurement is between 3mm and 5 mm); and finally *fragmentary* (between 2mm and 3mm). Any other length less than 2mm is excluded.

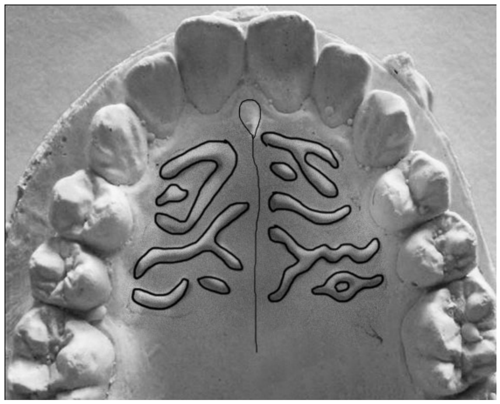


Figure 12 An illustration of the palatal rugae outlines.

Researchers are using markers to outline the rugae's shape on the stone cast.

In Figure 12, you will see more about the previous researchers' shapes and curves of the palatal rugae inside the palate. Although this part of biometrics based identification is poorly investigated, there are some literatures listed in the next part of this chapter to deeply understand the palatal rugae in detail. Moreover, in the next part of this chapter, a full description about the palatal rugae and the field of the palatal rugoscopy. Also, this paper is to support the palatal rugae role in the field of forensic science to be not only a promising tool for human identification, but also a team player with the other types of biometrics based identification tools to be a part of the multi-model biometrics.

2.1.8 The Future of Biometrics

No doubt that the biometric technology is moving forward. System prices will continue to decrease and the size of machines will get smaller. From another hand, the rate of identity matching will improve. The main factor of accepting such improvement is the need of a better recognition rate. Therefore, more demanding application are in need to create more sophisticated algorithms that left the matching techniques to higher. For demanding software, multi model systems will expand to fulfill the gaps of having multiple biometrics for each individual and to provide an optimum level of security and convenience to users. Otherwise, multiple verification, such as using the whole fingerprints, will be in use to consolidate the recognition process precision. It is also predicted that the use of biometrics will take over the current personal verifications such as passwords, keywords, PINs, or any Internet access; if the manufactures' prices of scanners or censors are reducing. The biometrics promise is to make authentication simpler and the personal information or any important data in a higher level of security.

2.2 Palatal Rugae

Palatal rugae, also called "plicae palatinae transversae" refer to the irregular elevations of the mucosal ridges that take its place in the anterior part of the hard palate and behind the incisive papilla; parted in both sides by palatine raphe [1,2,3]. A lot of studies showed that the pattern of the palatal rugae are unique within each individual since they formed a specific pattern that differentiate it from one person to the other like fingerprints [2,3,5,6].

The formation of these ridges took phases in order to get its final shape. It started in an early phase where it put together in human life [8]. Ridges appear toward the third month of intra womb life. In the prenatal stage, the ridges shapes are relatively salient. At birth, the palatal rugae are well formed with an idealistic pattern and during adolescence they took their final shapes of each person. After the final formation, slight changes appear regarding to the regular growth, which is in the length of the rugae, but the shape still maintained.

Anatomically, the position of the palatal rugae is astonishing due to the mouth-surrounding parts like lips, cheeks, tongue, buccal pad of fat, teeth, and bones in upper and lower jaws. All of those parts give the palatal rugae a well-protected atmosphere from high temperature and trauma. Moreover, the characteristics of the palatal rugae pattern are not affected by the changes that happened to the surrounded teeth or their loos, but in sometimes palatal rugae adjust itself on the anterior arch of the palate and get a slight change in position after tooth extraction but not the shape. Furthermore, in some cases the extraction can bring a minor effect on the direction of the palatal rugae.

Physiologically, the palatal rugae assets in the process of swallowing, taste perception by improving the relationship between the food and the taste receptors, in suction for infants, and participate in speech. Moreover, Almeida reported that the configuration of the palatal rugae makes it a useful tool for land marking for dental cast analysis [24].

2.2.1 Morphology

In human embryos, the palatal rugae appears in the third month of intrauterine life. Where the first rugae are prominent next to the incisive papilla in human embryos of 3.2 cm CRL (crown rump length) [8]. It gets it shape from the covering connective tissue in the palatal process of maxillary bone [16].

In the human embryos of 5.5 cm CRL, there are five to seven symmetrically disposed ridges; it started with the anterior once at the raphe, the others are more sidelong with the respect of the anterior ridges. In the end of the human embryos development stages, the pattern of the palatal rugae get more compressed, therefore more randomized. Also, the pattern of the posterior rugae disappears and those in the anterior part of the palate became considerably more obvious and compressed [17]. The regulation of the collagen fibers orientation in rugal morphogenesis has been attributed to the influence of certain genes [20].

In general, the palatal rugae are relatively distinguished taking over much of the area of the palatal shelves. As growth continues, palatal rugae closed to the anterior part of the secondary palate [17]. Once the palatal rugae got to it final position in the anterior part of the palate, the shape and position of it remain generally maintained. From another hand, palatal rugae may experience some changes in the length during the regular growth [18].

It has been obtaining that palatal rugae get their typical direction pattern at birth and develop their final shape in adolescence. Thereafter, they remain stable throughout person's life until death [21]. However, the idea of stability of the palatal rugae patterns is a matter of discussion between the investigators in the literatures. Some investigators inducted that the palatal rugae position are closely related to the position of teeth. Therefore, the extraction of other teeth is bringing a change in the original position or direction of the palatal rugae [22]. From another hand, other investigators concluded that palatal rugae keep it position and direction after extraction of other teeth and it not affecting the orientation of the rugae in general [21, 23].

Other studies suggested that posterior rugae more likely keep their position than the anterior because of the nature of teeth growth that put pressure upon the anterior part of the palate [21]. However, it was also noted that the first rugae are the most stable [24]. Furthermore, pattern changes were observed following extreme finger sucking during infancy and orthodontic treatment due to persistent pressure [9, 25].

2.2.2 Historical Review

The palatal rugae were described for the first time in general anatomy in 1732 by J.B Winslow [1]. In 1775, Santorini was the first investigator who illustrated the palatal rugae in the shape of 3 wavy lines goes across the midline of palate [2]. These shapes of ridges attracted Harrison Allen's attention. Harrison was the first who suggested that the palatal rugae could be used as a personal identification in 1889 [3].

After discovering the uniqueness and the fascinating characteristics of the palatal rugae, Goria putted the first palatal rugae classification system in 1911. The patten of the palatal rugae was categorized in two ways: targeting the number of rugae and targeting the size of rugae zone with respect of teeth. Furthermore, the palatal rugae was distinguished into two types: simple and primitive [4].

In 1932, a Spanish investigator named Trobo Hermosa proposed the term "Palatal Rugoscopy" that specialized in the study of palatal rugae and for the purpose of establishing persons' identification [5]. Moreover, in 1937, Carrea found that the pattern of rugae start to develop by the third month of prenatal life and remain having the same shape until death [6].

Another fact that fascinate about the palatal rugae is the variation of rugae count on each side of the human palate is between three to five and the palatal rugae are never cross the mid palatine raphe in the first third of the upper jaw [5]. After establishing the field of rugoscopy, many attempts have been taken in order to investigate the palatal rugae until 1955; where Lysell was the first whom scientifically classified the palatal rugae shapes as the palatal rugae patterns [7]. Thomas & Kotze added in 1983 the latest major update for the palatal rugae classification. Their finding was an extension for the field of palatal rugoscopy by extensively describing everything related to the palatal rugae. They studied the rugae as a single element and extracted the following elements that related directly to the rugae as a unit. The rugae dimension and prevalence; Primary rugae detail; the rugae pattern dimension; Angle of divergence; finally, the dental arch and palate dimension [6, 7, 15].

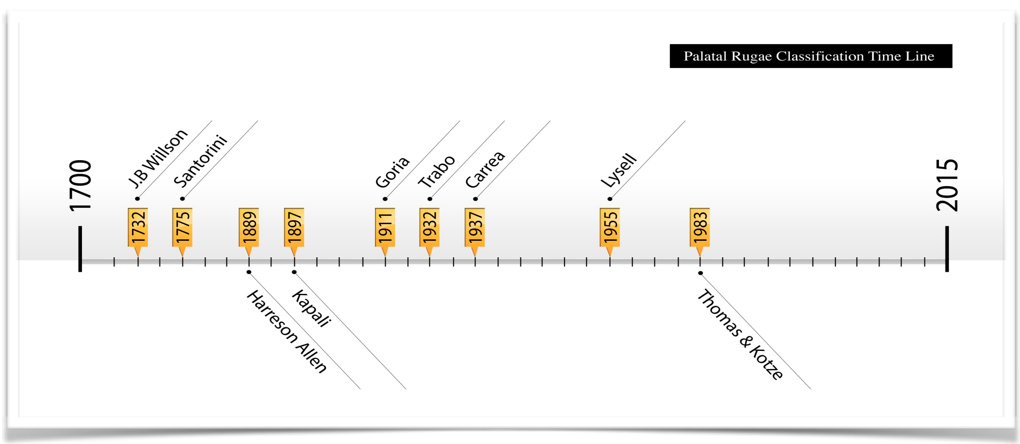


Figure 13 Most Popular Palatal Rugae Classification Time Line

since 1732 by J.B Willson until 1983 By Thomas and Kotze; since then no updates about a new classification for the palatal rugae biometrics base identification.

2.2.3 Ethnics Variation

Anatomists have shown interest in the evolutionary development of PR, but surprisingly studies relating to it have been scarce in dental literature. A semi-quantitative method of analysis by Szilvassy & Hauser [54], based on an earlier method of Reuer [55] indicates the presence of inter-racial differences in PR and its pattern. Ethnic variation was also reported by Thomas C.J. based on Lysells classification. Inter and intra population analysis between Greeks (South Europeans) and South African (Swazi, Bantu) population suggested obvious ethnic differences by Hauser G *et al* [17]. The Swazi's have stronger and complex main (primary) rugae than the Greeks. There was an association observed between the primary rugae and the palatal size of this population.

Kashima K. [56] compared the palatal rugae pattern with the shape of the hard palate pattern in Japanese and Indian children. The PR, incisive papilla and the shape of the hard palate were measured using Yamazaki [57] method following Lysell's and Hausser's classification. The differences according to population (1-5), palatal findings (6) and sex (7) are summarized as follows:

1. The number of primary rugae seen in Japanese children is often more than that seen in Indian children, but the number of transverse palatal rugae was the same.
2. There were differences between Japanese and Indian children in the primary rugae shapes, the posterior limit of the rugae zone, the number and position of the secondary rugae and fragmentary rugae.
3. The incisive papilla of the Japanese children was a little larger than those of the Indians. Generally, the incisive papilla of the two populations was pear-shaped but the Indians showed more variability.

4. The palatal raphe of the Japanese was wider than those of the Indians. The number of children with no palatal raphe branch was large for Indian children, but small for Japanese.
5. The frontal view of the hard palate of Japanese children was broad and that of Indian children was narrower. The palatal shape of the two populations was almost trapezoid. The occlusal view in both the populations was broad and U-shaped.
6. There were many transverse palatal rugae in the two populations on the left side. The posterior limit of the ruga zone of the left side was shifted further back than the right side.
7. There were no significant differences between sexes for most of the above points.

Statistically significant association between rugae forms and ethnicity was reported by Kapali and colleagues (28). They compared the number, length, shape, direction and unification of rugae in Australian aborigines and Caucasians. The mean number of primary rugae in Aborigines was higher than in Caucasians, although more primary rugae in Caucasians exceeded 10 mm in length than in Aborigines. The most common shapes of primary rugae in both ethnic groups were wavy and curved forms, whereas straight and circular types were least common. The data compared with the other studies is summarized in the table below:

Table 3 Average number of palatal rugae in different Ethnicities

Ethnic groups	Number of subjects	gender	Age range	Number of PR		
				Left	**Right**	**Mean**
Japanese	50	Male	-	4.7	4.7	4.7
	50	Female		4.3	4.5	4.5
Central Europeans	50	Male	10 - 50	4.3	4.2	4.3
	50	Female		4.3	4.4	4.4
Swedes	50	Male	21 - 24	4.5	4.3	4.4
	50	Female		4.3	3.9	4.1
Australian Aborigines	50	Male	14 - 20	5.2	4.8	5
	50	Female		5.2	4.6	4.9
Australian Caucasians	110	Male	11-57	4.3	4.3	4.3
	110	Female		4.3	4.3	4.3

The average number of palatal rugae in different Ethnicities: Japanese, Central Europeans, Swedes, Australian Aborigines, Australian Caucasians. (Data from Lysell (1955) [21] and Kapali S et al. (2001) [9]

Table 4 Demographic comparison of individual palatal rugae characteristics Based on Lysell classification

No. of subject		100	220	30	30	50	50
Ethnicity		Australian Aborigines	Australian Caucasian	Indians Madhya Predesh	Indians Kerala	Indians Mahara-shtra	Indians Karnataka
Shape	**Stright**	**34** *(3.6%)*	**176** *(15.2%)*	**38** *(25.3%)*	**25** *(16.3%)*	**154** *(31%)*	**116** *(23.8%)*
	Curved	**221** *(23.2%)*	**298** *(25.8%)*	**35** *(23.3%)*	**39** *(25.4%)*	**212** *(42.7%)*	**108** *(22.1%)*
	Wavy	**531** *(55.8%)*	**469** *(40.6%)*	**43** *(28.7%)*	**54** *(35.3%)*	**127** *(25.6%)*	**257** *(52.7%)*
	Ring	**34** (3.6%)	**33** (2.9%)	**9** (6%)	**8** (5.2%)	**4** (0.8%)	**7** (1.4%)

	Unification	**132** *(13.9%)*	**180** *(15.6%)*	**25** *(16.7%)*	**27** *(17.6%)*	**-**	**-**

Palatal rugae characteristics Based on Lysell classification, Shwetha K. S et al [53] assessed the length, shape and unification of rugae in Mysorean (Indian) and Tibetan people. These parameters showed racial differences in this population too.

2.2.4 PR in Forensic Odontology

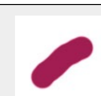
Human identification has become essential for both social and legal human relationships. The identity contains of an individual characteristic that individualizing a person or something. It is a set of properties that make something or someone equal only to itself. The human identification determine by technical or scientific measurements that a person is the only one, and not another, who have the same characteristics and structure [26]. There are five requirements to perform any identification process: Unicity, immutability, persistence, practicability, and possibility of classification [27].

In the field of forensic identification, the use of DNA, fingerprints, visual identifier, and dental records are the most common techniques used allowing the investigation to get accurate results about whom, when, and even why a crime occurred. However, there are a lot of cases where identification cannot be determined by neither fingerprints nor dental records. It is actually a difficult task when it comes to major traumas such as act of terrorism or in the case of fire, drowning, or big accidents. In fact, the identification process becomes progressively harder and sometimes impossible to be accomplished when the nature disasters hits hard. Earthquakes, tsunamis, volcanos, and tornados are other example of such traumas that human can face anytime anywhere [10].

2.2.5 Classification

The palatal rugae classification had been classified since 1911, where Goria categorized the rugae in to two ways. He specified the number of rugae that are near to the third part of the anterior part of the palate. He also specified the extent of the rugae zone relative to the teeth. Moreover, Goria distinguished that there are two types of rugae exists: Simple and primitive. Those types are completely depends on how complex the rugae shape [6]. According to Trobo, the palatal rugae classification contains of two groups: simple and compound. The simple rugae shapes were classified by types: A, B, C, D, E, F. From another hand, the compound rugae shapes were took it form by the union of two or more simple rugae and it classified by the Table 5[8]. The following table 1.0 is shown the way that Trobo classified the palatal rugae.

Table 5 Trobo classified the palatal rugae according to their simple shape

Classification	Rugae Type	
Type A	Point	
Type B	Line	
Type C	Curve	

Classification	Rugae Type	
Type D	Angle	
Type E	Sinuous	
Type F	Circle	
Type X	Union	two or more shapes together

Lysell suggested a classification of the palatal rugae where it depends on the length of the rugae. His classification concluded into four shapes. Primary rugae, where the rugae length is 5mm and more. Secondary rugae, where the rugae length in the range between 3mm and 5mm. Fragmentary rugae, where the rugae length goes between 2mm to 3mm. Finally, any rugae smaller than 2mm are disregarded [4].

Table 6 Lysell classified the palatal rugae depending on the rugae length.

Rugae type	Measurement (mm)
Primary	5 and more
Secondary	3 - 5
Fragmentary	2 -3

Kapali classification was made according to the palatal rugae's *length*, *shape*, *direction* and *unification form*. The palatal rugae shape divided into: curved, wavy, straight, and circular [9]. Where the straight was mentioned as the way that palatal rugae run directly from their origin to termination. The curved had a crescent shape and curved gently. Also, the wavy have a slight curve at the original or termination of curved rugae as well. Lastly, the circular shape; where rugae form a definite continuous ring as all shown in (Table 7).

Table 7 Kapali classification for the palatal rugae according to their shape.

Straight	They run directly from their origin to termination.
Curved	They had a crescent shape and curved gently.
Wavy	There was a slight curve at the origin or termination of curved rugae.
Circular	Rugae that form a definite continuous ring were classified as circular.

According to Kapali classification, the palatal rugae length divided into three types: primary, secondary, and fragmentary [9]. This specific measurement was made first by Lysell in 1955. However, Kapali added in 1997 that the primary rugae divided into two types: A- where the length of the palatal rugae is 5-10 mm; B- where the length of the palatal rugae is 10mm and more.

Primary rugae	(A: 5–10 mm; B: 10 mm or more).
Secondary rugae	3–5 mm.
Fragmentary rugae	less than 3 mm.

Table 8 Kapali classification for the palatal rugae according to their length.

Kapali also classified the palatal rugae according to their direction. There are three types of direction regarding the palatal rugae direction. First, forwardly directed rugae; where the palatal rugae is associated with a positive angle toward the incisive papilla. Second, backwardly directed rugae; where the palatal rugae is associated with a negative angle backward direction of the incisive papilla. Third, perpendicular rugae; where the palatal rugae is associated neither to a positive nor a negative angle with respect of the incisive papilla [9].

Table 9 Kapali classification for the palatal rugae according to their direction.

Forwardly directed rugae	associated with positive angles.
Backwardly directed rugae	associated with negative angles.
Perpendicular rugae	associated with angles of zero degrees.

Lastly, Kapali classified the unification of the palatal rugae into two types. First, diverging; where two rugae have the same origin from the midline but immediately branched. Second, conversion; where two rugae have different origin but joined on their later portion as one rugae [9].

Diverging	If two rugae had the same origin from the midline but immediately branched.
Converging	Rugae with different origins from midline, but which joined on their lateral portions.

Table 10 Kapali classification for the palatal rugae according to their unification.

Nonetheless, another investigator classified the palatal rugae according to their form. Carrea classification were divided into four types depending on the direction that rugae took. The classification includes four types. Type 1, where the rugae have a posterior-anterior direction. Type 2 where the rugae is perpendicular to the raphe. Type 3 where the rugae have an anterior- posterior direction. Finally, Type 4, where the rugae have several directions [10].

Type 1	Rugae have a posterior-anterior direction
Type 2	Rugae perpendicular to the raphe
Type 3	Rugae have an anterior-posterior direction
Type 4	Rugae directed in other directions

Table 11 Carrrea classification the palatal rugae direction.

Martins dos Santos classification depended on the form and position of each palatal rugae. In his classification, each palatal rugae have its own characteristic as the following types. One initial rugae, where the position of this rugae is the most anterior one on the right side of the palate represented by a capital letter; Several complementary rugae where they follow the initial, but represented by numbers. One sub-initial rugae, where it took its place on the most anterior position in the left part of the palate represented by letters; Several sub-complementary rugae, where other left rugae are represented by numbers [10]. The following table 2.12 is shown the way that Martins dos Santos classified the palatal rugae based on form and position.

Table 12 Carrrea classification for palatal rugae shapes.

Rugae type	Anterior position	Other Position
Point	P	0
Line	L	1
Curve	C	2
Angle	A	3
Circle	C	4
Sinuous	S	5
Bifurcated	B	6
Trifurcated	T	7
Interrupt	I	8
Anomaly	An	9

e.g.: (A432), where it means that the most anterior rugae in an Angle shape rugae followed by Circle, Angle, and Curved.

Another investigator by the name Lo'pez de Le'on proposed that there is a relationship existed between the person's personality and the palatal rugae morphology. In his proposal, there were four known types of palatal rugae based on the personality perspective: bilious personality rugae which represented by the letter B; Nervous personality rugae that represented by the letter N; Sanguinary personality rugae denoted by the letter S; and Lymphatic personality rugae represented by the letter L[10]. Morphologically, those four types define the profiles of all human beings personalities. Moreover, each type has a fixed characteristics associated with it. That is, anyone who displays a predominance of one temperamental type must have certain behavioral and psychological and physiological characteristics [11]. The letters B, N, L, and S, donating those for personalities. Added to the letters of personalities, the position of the rugae. represented by l and r for the left and right side of the palate. Furthermore, the personality and the position is followed by a number, which determine the palatal rugae in each side. An example of that would be Bl4, Nr5, and so on. da Silva, from another hand, did an easy classification which divide the palatal rugae into two groups according to the rugae number. Simple, which is numeric from one to six, and compound, which hold the meaning of each numeric field such as: line, curved, angle, circle, wavy, and point [10].

Table 13 da Silva classified the palatal rugae depending on the rugae number.

Simple	Compound
1	Line
2	Curved
3	Angle
4	Circle
5	Wavy
6	Point

Another example about easy classification was the one made by Basauri. His classification was very easy. Basauri classification differentiates between the principle rugae and the accessory rugae. The principle rugae is the more anterior rugae labelled with letters and the accessory rugae, which concerns all remaining rugae, where labelled with numbers. The reading of the palatal rugae in this classification starts from the right side of the palate [12].

Table 14 Basauri classified the palatal rugae depending on the labelled rugae.

Principle Rugae	Accessory Rugae	Rugae Anatomy
A	1	point
B	2	line
C	3	Angle
D	4	Sinuous
E	5	Curved
F	6	Circle
X	7	Polymorphic

Another classification was made by Cormoy. His system classified the palatal rugae according to their size into: principal rugae (over 5 mm); accessory rugae (ranging from 3 to 4 mm); and fragmental rugae (with less than3 mm length). Moreover, he described each palatal rugae by it's form (line, curve, and angle), origin (medial acuteness), and the direction of each rugae. Although his classification was complete, its use dose not lead to an elaboration in the field of rugoscopy [13]. Table 15 describes the way that Cormoy use the measurement of the rugae size to identify the rugae's type.

Table 15 Cormoy classified the palatal rugae according to the size.

Rugae type	size (mm)
Principel rugae	5 and more
Accessory rugae	3 - 4
Fragemental rugae	less than 3

Several other classifications have been proposed but none really able to fill the gap in the way that the palatal rugae criteria have. However, the most used classification have been used to extract the palatal rugae properties and use it as an identification is the one proposed by Thomas and Kotze. They used Lysell's classification with minor variations. Thomas added features such as crosslinks. They presented a detailed classification consisting of five main aspects: (1) The rugae dimension and prevalence; (2) Primary rugae detail; (3) The rugae pattern dimension; (4) Angle of divergence; (5) Finally, the dental arch and palate dimension [4, 6]. All in which has its own specification. Starting with the rugae dimension and prevalence, Thomas and Kotze studied the rugae as a single element and extracted the following elements that related directly to the rugae as a unit. Each rugae have its own length, which measured using the same classification that Lysell used; which are: primary (5mm and more), secondary (between 3-5mm), and fragmentary (between 2-3mm). Less than 2mm are disregarded. Also, each ruga has its own area; determined by the surface area of the primary rugae. Another key criterion of the rugae as a single unit is the prevalence of the palatal rugae, where they counted only and recorded the number in each category (primary, secondary, and fragmentary) and not the total number in each side. Thomas and Kotze also designated the rugae anatomically by:

- Annular rugae: which considered annular, the rugae must form a specific ring,

- papillary: A rugae is termed ‘papillate’ when three or more slots overpass the rugae at any depth, but not down to the surrounding mucosal surface,
- Crosslink: his is small rugae that is a distinct entity and joins two rugae, usually at a right angle.
- Brunches: A branch extends 1 mm or more from its origin (that is, the parent ruga) in a lateral direction.
- Unification: This process occurs when two primary rugae are joined at their origination points and then diverge laterally.
- Breaks: If a papillary rugae cleft extends down to the level of the surrounding epithelium (less than 1 mm), it becomes a break.
- Unification with non-primary rugae: This is a convex or concave unification of a primary rugae and a rugae that is between 1 and 5 mm in length [6,7,15].

The pattern dimension is no different story, the rugae dimension measured by the distance between the palatal rugae and the incisive papilla. From that point of view, three types of dimensions were measured: (1) Distance between most anterior point on incisive papilla and most anterior point on rugae pattern regardless the side; (2) The distance between the posterior border of the last primary or secondary rugae and the incisive papilla; (3) Lastly, the distance between the posterior border of the last rugae, including fragmentary rugae, and the incisive papilla [4].

Another aspect of Thomas and Kotze classification was about the angle of divergence, where it measured by the degree between the line joining incisive papilla and the line formed by the medial palatal raphe with the origin of the most posterior primary or secondary rugae on one side of the palate [6].

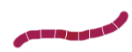
Rugae	Shape
Straight	
Curved	
Wavy	
Annular	
Papillary	
Crosslink	
Branches	
Breaks	
Converging	
Diverging	

Table 16 Thomas and Kotze classification.

Dental arch and palate dimension were measured by three elements with the respect of the palatal arch: Width, where line joining the tips of mesio-palatal cusp of permanent maxillary first molar or deciduous second molar is used to project a point below and perpendicular to it on the gingival margin to determine the width[14]; Depth, which can be measured by a point below and perpendicular to line joining the tip of mesio-palatal cusp of permanent maxillary first molar or the deciduous second molar on mid palatal raphe; Finally, the center, where a perpendicular distance between the line joining the tips of mesio-palatal cusp of permanent maxillary first molar and the point on mid palatal raphe[14].

2.2.6 Measurements and Tools

Palatal rugae pattern analyses can be done on a photograph of the rugae area, dental cast. On the dental cast the rugae are marked using a HB pencil. After delineating the individual rugae the cast is either scanned on a flat-bed scanner or directly viewed with naked eye for analysis [57,58]. Palatal rugae analysis can be carried out qualitatively and quantitatively. Most of the studies done in the literature have utilized qualitative analysis of the palatal rugae. The most acceptable classification used was that of Thomas and Kotze (1983) modification of Lysell's classification (1955).

- Qualitative characteristics

The qualitative characteristics of individual rugae mentioned below are a combination of classifications by Thomas and Koetze (1983), Hausser *et al* (1989) and Kapali *et al* (1997). Various characteristics of rugae are observed as point, straight, curved, wavy/sinuous, angled, unification, circular, converging, diverging, composed and non-specific

- Quantitative characteristics

The total number of rugae is counted without considering the side of the palate. Length analysis: rugae are measured in a straight line between the origin and termination and are grouped into three categories [29, 30].

Primary: 5mm or more;

Secondary: 3-5 mm;

Fragmentary: 2-3 mm.

2.2.7 Biometrics Identification Base Criteria

What makes biological measurements qualify to make a biometric identification? This question have been a core discussion around the agreement about which part of the human body is applicable and considered to be a biometrics based identification. The following are the main criteria that makes biometrics based identification valid in the field of forensic science:

Uniqueness: No two persons should be the same in term of the characteristics.

Universality: Every person should have the characteristics.

Permanence: Characteristic should be invariant with time.

Collectability: Characteristic can be measured quantitatively.

Performance: The achievable identification accuracy.

Acceptability: To what extent people are willing to accept the biometric system.

Circumvention: How easy it is to fool the system by fraudulent technique. (R. Clarke, 1994).

Chapter 3: MATERIALS AND METHODS

3.1 Materials

3.1.1 Study design

This is an observational study among a selected 3D casts for a community who lives in Abha, Saudi Arabia. It is designed to compare the palatal rugae pattern of the permanent dentition of Saudi patients using modern standardized three-dimensional cast of patients and apply all criteria of the biometrics on the three dimensional object in order to validate it as a biometrics measurement tool in the field of forensic science. Thus, extract identification. The main aim of the study is therefore to investigate the uniqueness of the palatal rugae to extract a biometric based identification based on those ridges. Moreover, to create a scan-able bar coding system for dental record keeping and subsequent patient filing system in any dental clinics for the purpose of establishing a central database that contains all identification to be a resource for the field of forensic odontology. By that, there will be an incremental level of acceptance to the palatal rugae based identification to be one of the multimodal biometrics. Therefore, the gap of accepting such element will be solved.

3.1.2 Study area and population

The study comprised of samples upper palate models that collected from King Khalid University, departments of orthodontics. Where all samples are publicly free for use for educational purposes. The sample is collected equally between 12 females and 12 males. The study population comprised male and female subjects aged between 18 and 40 years old because the stability is ensuring for such ages especially in the matter of length. Although, all shapes still remain from the birth until the death [12]. The study population originally was selected from among orthodontic patients attending consultant clinics and postgraduate orthodontic teaching clinics. Their ages were taken from the dates shown on their pre-treatment dental casts.

3.1.3 Sample size

Only good quality study 3D models were selected from KKU orthodontic database randomly between 12 males and 12 females to used and examine palatal rugae pattern. Study 3D models had already been made for all participants as part of a routine orthodontic assessment. On accepting the candidate for inclusion, the age and sex were recorded already in the metadata for each sample to ensure that the original information still exist with each subject. Also, each subject was then given a code number to allow the measurements to be undertaken ‘blind’. So far, 24 3D models were selected. 12 male and 12 female between the age of 18 and 40.

3.1.4 Sampling procedure

The sampling methodology was done by collecting three main parts. The usage of these three components is the pattern of the identification code that will be generated for each subject at the end. Each part is recorded separately to extract initial measurements for standardizing the land marking point for which the other measurements will use as a starting point. The three procedures are:

- Recording the measurement of each incisive papilla as a landmark for each 3D model using AutoDesk Maya Studio to use it as a starting point for other measurements. All lengths are measured by the distance tool in (mm) and collected under one table named : incisive_papilla_landmarking_length to get 24 lengths of the all incisive papilla in the subjects' models.

- Recording the shapes of all palatal rouges using Lysell's classification (1955) and collect it all under another table for each subject named "Cases_Shapes" including the number of each rugae in each side and the length of each rugae using the actual length measurement tool "ArchLength" inside AutoDesk Maya Studio.

- Finally, recording the ratio of distance between the first right rugae and the incisive papilla using a triangular shape connecting between (the incisive papilla, the start of the FR rugae, and the end of the FR rugae).

After collecting all data from each procedure, a concatenation of each record from the previous table will generate a unique identification for each individual.

3.1.5 Inclusion criteria

Subjects were collected according to the following criteria:

Location: From one demographic area (Abha, Aseer Region, Saudi Arabia).

Ethnicity: Arabs/middle eastern.

Sex: Both sexes.

Age: Similar ages (15 – 40 years old).

Orthodontic treatment: No history of orthodontic treatment.

Occlusion type: No selection of particular dental occlusion or skeletal pattern was made.

Study models: Good quality study models were required for all subjects; thus, any defective study models would be excluded.

Patients with any syndrome: Not included.

3.1.6 exclusion criteria

- Subject who have a fixed orthodontics appliance.
- Subject with congenital malformation or defects of the palate.
- Previous orthoganthic surgery.
- **Study models:** Good quality study models were required for all subjects; thus, any defective study models would be excluded.
- 3D models with fuzziness, blurred edges, and low scanning quality.

3.2 Methods

3.2.1 Data Selection

The study utilized a modern three-dimensional geometric morphometric analysis technique to obtain measurements of each palatal rugae and especially the first right rugae (FRR). Palatal rugae pattern analysis can be done by taking a digital impression with sophisticated intra-oral scan for the upper jaw where the rugae pattern takes it place. The machine that doses this operation is 3Shape Intra-Oral Scanner TRIOS (figure 3.1, 3.2).

Figure 14 3Shape Intra-Oral Scanner TRIOS .

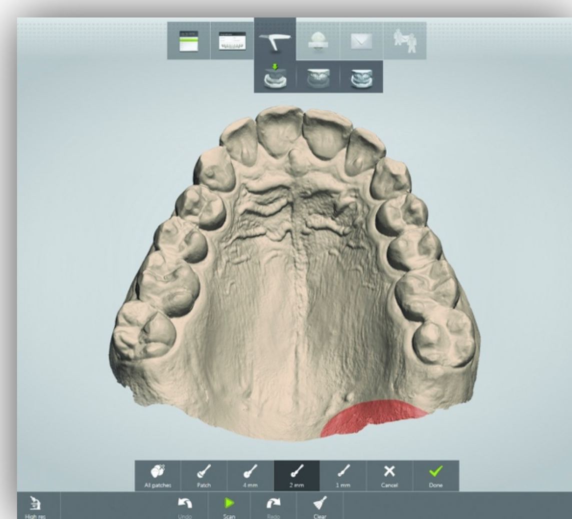


Figure 15 Sample from the software (Orthoanalyzer-TRIOS)

The following are the main system components used in the present study:

- Three-dimensional dental scanner (R640) (3Shape 2009).

- Personal computer.

- Software:

- Orthoanalyzer (3Shape 2009)- Adjusts scanned images.

- Maya Studio (AutoDesk 2015).

- Matlab (The MathWorks, Inc. 2015) - image processing and biometrics based identification usage.

- MeshLab v1.2.1 (Cignoni 2008)- Converts scanned images.

- Landmark.exe (Wiley 2005)- Landmark identification.

- MorphoJ 1.02c (Klingenberg 2010) – Geometric morphometrics and statistical analysis.

- Morphologika2 v2.5 (O'Higgins 2006) – Shape visualization.

- SPSS 18.0 (Pallant 2007) – Statistical analysis.

3.2.2 Data Acquisition

Scanning requirements

The scanning of a dental study model will be performed using an optical scanning system (3Shape), in which laser planes will be projected onto the upper part of the palate. High-resolution digital cameras acquire images of the lines created on the participants' palate. The Orthoanalyzer Software from (3Shape) automatically processed the images and created accurate and high resolution surfaced 3D models that includes a metadata about the participant.

Scanning procedure

The procedure taken in this study to ensure that the 3D information is within an accurate measurement for the purpose of studying the palatal rugae is by using a scanned stone casts where the model will be positioned on the articulating table and the laser projected an image of a line/series of points onto the surface of the model. This will be performed in darkness so that what was visible to the cameras was a red line on the surface of the model.

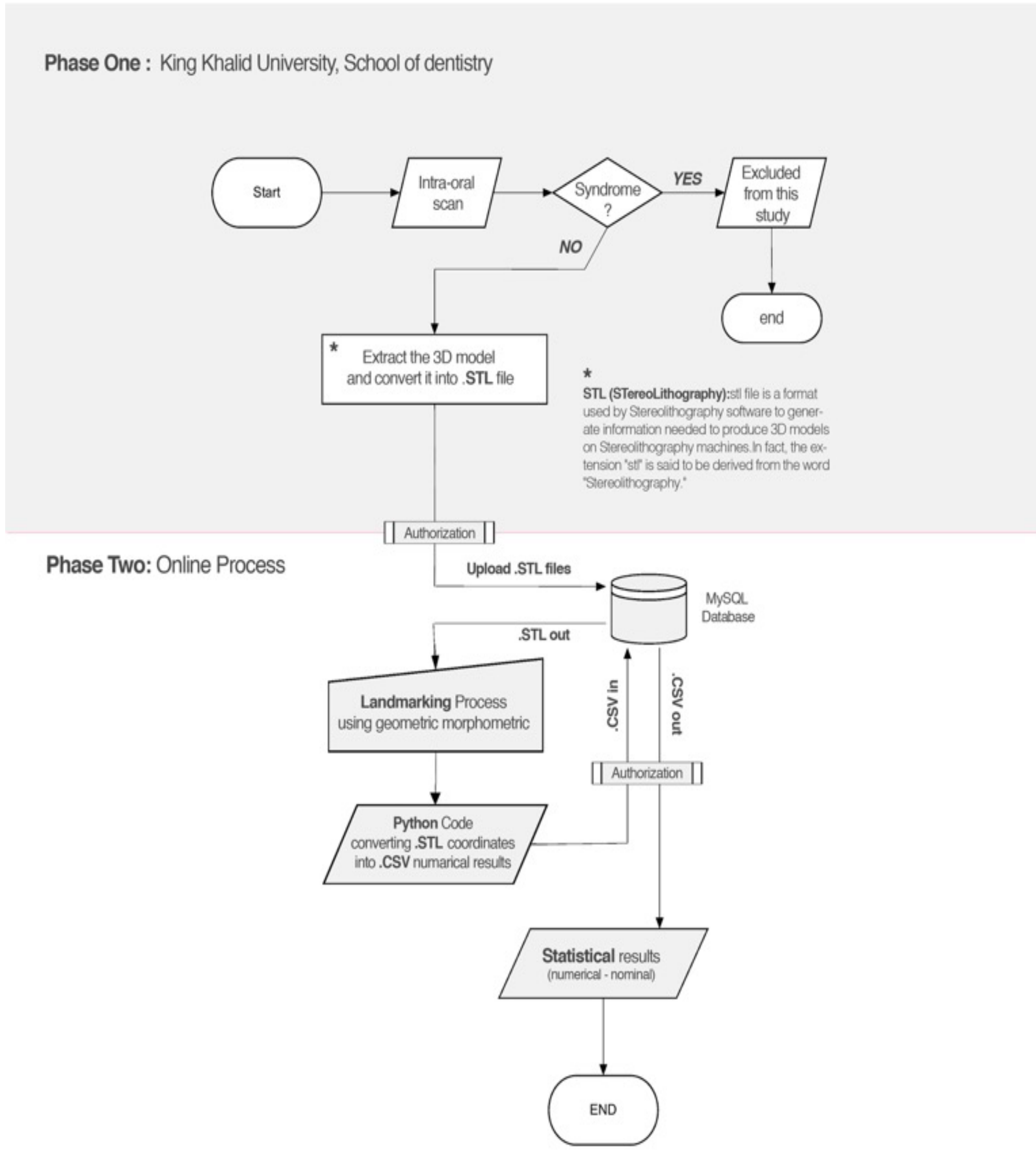


Figure 16 Data Selection and Data Acquisition for the palatal rugae samples

It generally divided into two phases: Phase one, where the data selected from the dental school in King Khalid University, Abha, Saudi Arabia. The second phase is the data acquisition for converting the 3D objects and collects the measured palatal rugae to prepare it for the next phase which is the data analysis and the identification extraction.

The two cameras will have positioned at an angle of approximately 45 degrees on either side of the projected image. Two scanning processes had to be executed during the complete cycle involved in generating the full digital upper study models. The first of these was the process by which many thousands of points are created in a three-dimensional space. Each of these points has x, y and z coordinates and make up the "point cloud". The second process will be a software process that converted the point cloud into a series of triangles. Each triangle will be constructed from three adjacent points in the point cloud. This process does not require the model to be placed in the scanner as the process is performed on the completed point cloud. When the triangles are created, algorithms which perform an extrapolating function add curvature to the triangular surfaces to mimic the smoothness and fluidity of naturally occurring surfaces. The resulting scanned models will be saved in [. STL] format which was converted into [. PLY] using MeshLab v1.2.1. The time taken to scan an upper model is approximately 2min 15sec. The time required for post-processing an upper model is approximately 1min. There are two steps involved in calibrating the scanner.

Landmark definition and identification

Anatomical landmarks provide the core information on morphology in biometrics based identification. They have to be accurately defined, precise and relate to the same anatomical features in every specimen [57, 58]. In this research project three main anatomical areas will be identified. They are palatal rugae, incisive papilla and mid palatine raphe.

Incisive papilla - a small fold of mucous membrane covering the incisive foramen situated behind and between the maxillary central incisors at the anterior end of the mid palatine raphe.

Palatal rugae - are mucosal folds that appear like ridges in the anterior part of the hard palate. They vary in shape and thickness. The maximum thickness of a rugae is considered the strength of the rugae. The various recognized shapes (characteristics) in the literature are summarized in Thomas and Kotze classification in the previous chapter.

Mid palatine Raphe - A narrow elevation that extends from the incisive papilla posteriorly over the entire length of the mucosa of the hard palate. The landmarks will be digitized by the same person using the PLY* file in landmark.exe (Wiley 2005) (33) and the coordinates will be later exported as simple data text files. The data text files with the landmark coordinates will be modified as required by the specific format of the programs used for the geometric morphometric analyses.

Formats of various programs are described in the help manuals/user guides. A data text file consists of the configuration of a matrix (*k x m*) in which the *k* rows represent landmarks while the *m* columns represent dimensions. The shape of a configuration matrix depends on the particular task or software that is being [57].

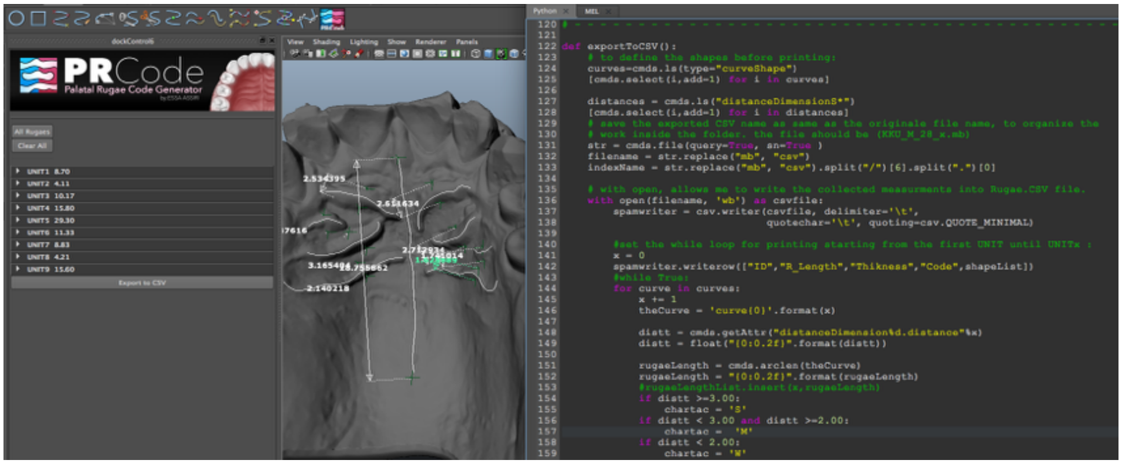


Figure 17 A Screenshot from Autodesk Maya Studio and Python Code for Extracting the Lengths of Palatal Rugae

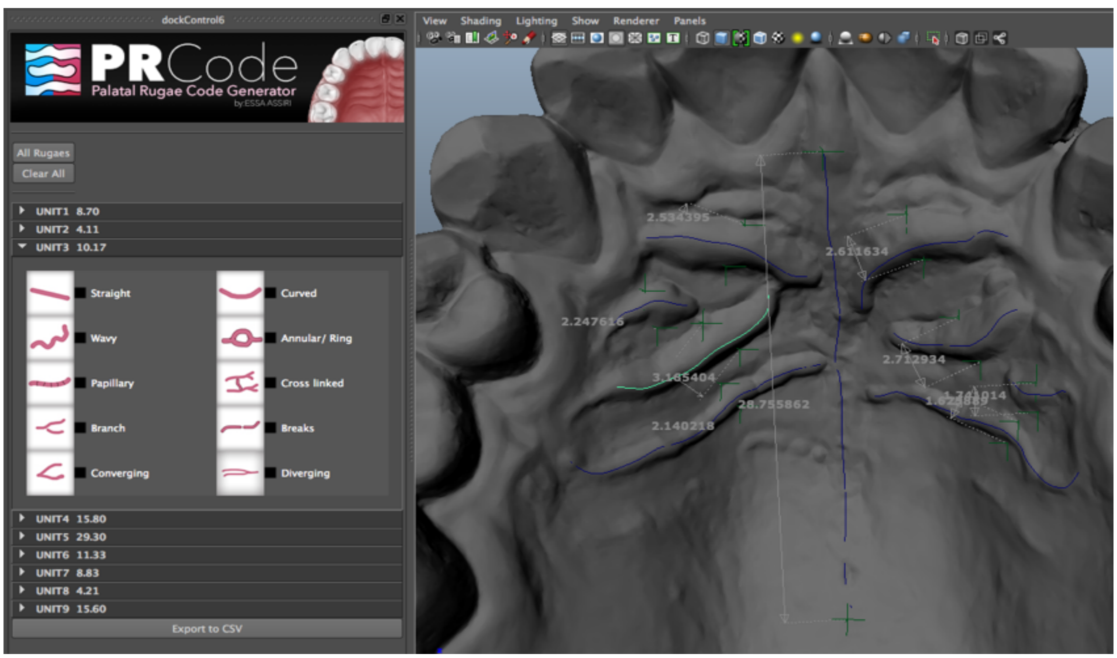


Figure 18 The Shape Selection of Palatal Rugae using the PRCode Python Code in Autodesk Maya Studio 2014

Chapter 4: RESULTS

The aim of this study is to validate and facilitate the palatal rugae to be used as identification in the field of forensic science as well as forensic odontology. Therefore, we need to go through the criteria of the biometrics based identification in order to see if the palatal rugae will fit to be used in this field in the first place. That's why, as a part of the result, we will start to compare and test if the palatal rugae is a valid biometrics based identification tool for the purpose of this study. After we proof that the palatal rugae is a valid biometrics tool, we can then extract the identification by concatenating the results from (shape, measurement, and ratio) of the palatal rugae pattern.

The following are the main criteria that make biometrics based identification valid in the field of forensic science:

Uniqueness: No two persons should be the same in term of the characteristics.

Universality: Every person should have the characteristics.

Permanence: Characteristic should be invariant with time.

Collectability: Characteristic can be measured quantitatively.

Performance: The achievable identification accuracy.

Acceptability: To what extent people are willing to accept the biometric system.

Circumvention: How easy it is to fool the system by fraudulent technique. (R. Clarke, 1994).

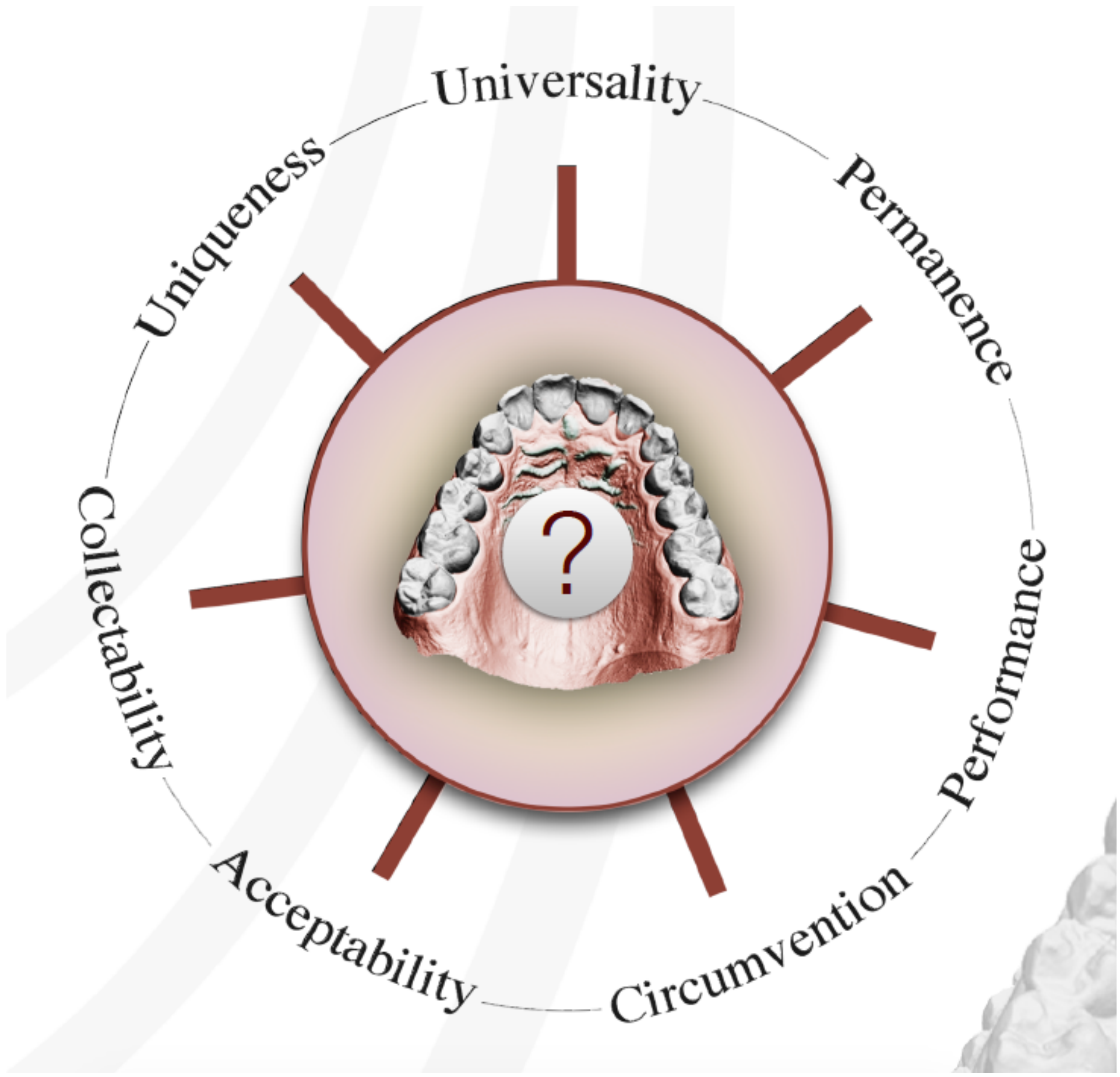


Figure 19 The Biometrics Based Identification Criteria

We are now going to study each criterion to see if the palatal rugae can fit to be a biometrics based identification before we go through other results.

4.1 Palatal Rugae as a Biometrics Based Identification:

4.1.1 Uniqueness

A lot of studies showed that the patterns of the palatal rugae are unique within each individual. Thus, the term palatoscopy or palatal rugoscopy is the name given to the study of the palatal rugae in order to establish the identity of an individual [12, 14, 21, 22].

4.1.2 Universality

It has been obtaining that palatal rugae get their typical direction pattern at birth and develop their final shape in adolescence. Thereafter, they remain stable throughout person's life until death [21, 22].

Other investigators came with conclusions in their study like Lysell in 1955 and Kapali in 1997 that the palatal rugae keep it position and direction after extraction of other teeth and it not affecting the orientation of the rugae in general [22, 26].

4.1.3 Permanence

Dental comparison is well recognized as regularly making a significant contribution to positive identifications in mass fatality incidents. Yet, it is not considered to be a valuable biometrics because of the nature of the dental treatment that change the person's dental compression overtime [25].

However, Palatal rugae after the changes occurring with extractions and tooth movement or any other orthodontic treatment do not significantly alter the pattern of the palatal rugae [77].

4.1.4 Collectability

It is most likely to collect palatal rugae images through dental visitation than other biometrics. 52.3% of adults reported that they had visited the dentist every six months the last few years, 15.4% reported once per year, and 11.0% reported once every two to three years. More than one in five (21.3%) said that they had not visited the dentist in the last few years [72].

4.1.5 Performance

It is evident from many studies that rugae are not markedly affected in survivors by the intensity of the fire and highlight the ability of palatal rugae to resist decomposition changes for up to seven days after death under ideal conditions of storage in mortuary [46, 33].

It also been reported that 93% of palatine rugae were normal and 77% of palatine rugae showed no color change among subjects with third degree pan-facial burns when examined after 72 hours stored in a mortuary at 5 degrees with 30 to 40 percent relative humidity [19].

4.1.6 Circumvention

It is hard to fool the system by using a fraud technique to duplicate the palatal rugae the anatomical position and the difficulty to reach and manipulate that mucosal part of human body [12].

Moreover, there are no literatures about any attempts of palatal rugae implant or attempt to do a replica. Also, because the palatal rugae usage is not a daily basic activity; therefore, the chance of altering it is most likely rare [23].

4.1.7 Acceptability

The only criteria that have some issue with establishing identification through the palatal rugae is the acceptability part of this technique. It is because the exposure of environment what makes other biometrics based identification acceptable to use as an identification. The idea of opening the mouth and have it scan rapidly makes it sound unacceptable. However, using this technique for specific purpose in the field of forensic odontology will open other doors to investigate unidentified bodies that been in major accidents like severe burn or long time drowning. From there we consider the usage of the palatal rugoscopy is a beneficial process to make sure of the identity of the found body.

From another hand, the lack of palatal rugae workflow standards causes the lack acceptance in the field of forensic science in general and the forensic odontology in specific. Therefore, the lack of usability in the law enforcement as well.

The official governmental site of biometrics.gov has established standards for biometrics. Those rules are the guideline for the developers in order to establish any new product for the law enforcement [87].

All literatures are considering the palatal rugae as a promising tool in the field of forensic odontology. However, no real attempt to develop palatal rugae based biometrics to be a part of the multimodal biometrics [88].

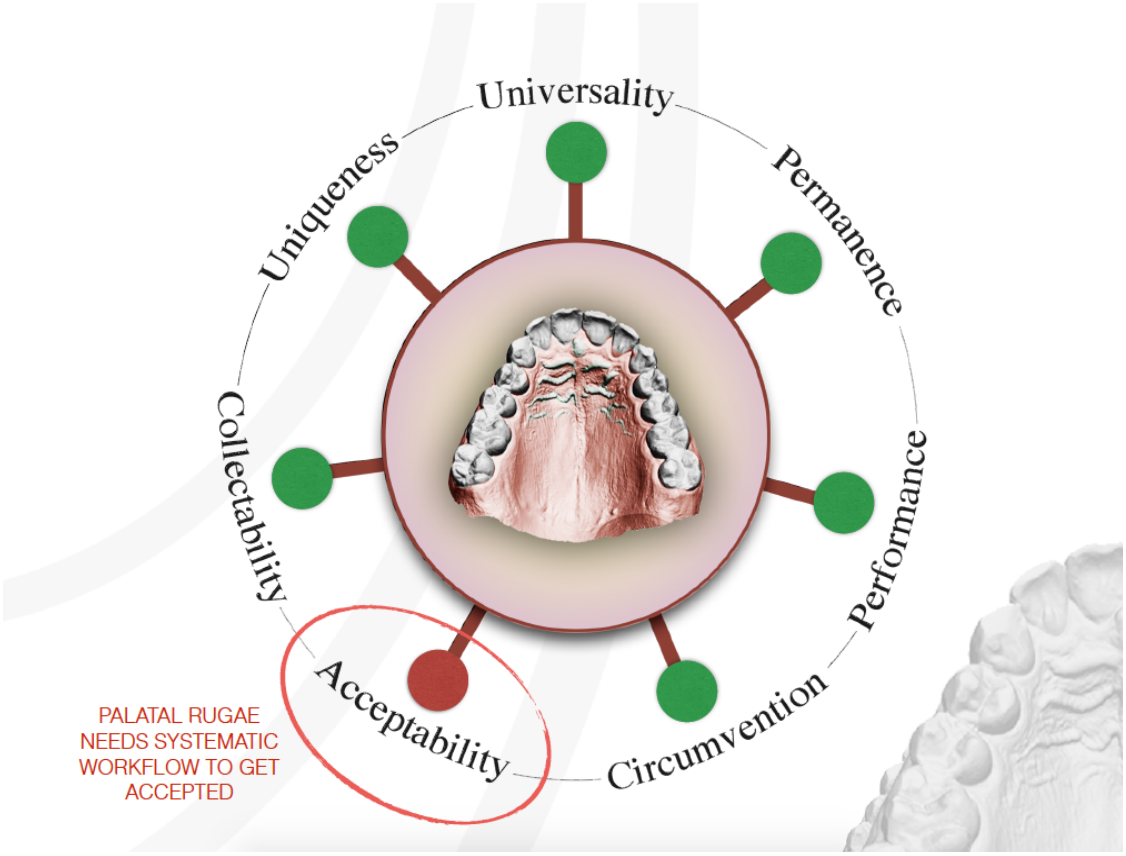


Figure 20 The Palatal Rugae Acceptance as a Biometrics Based Identification

4.2 Shape Analysis

In this section we will focus in ordering the priority of extracting the right information before doing the measurements for all palatal rugae. We will start by standardizing the position of the incisive papilla which is the small pear or oval shaped mucosal prominence situated at the midline of the palate, posterior to the palatal surface of the central incisors. According to previous studies, discrete papilla, papilla continuous with interdental papilla and papilla continuous with rugae are the three main shapes of incisive papilla. Therefore, a further study of the incisive papilla was needed.

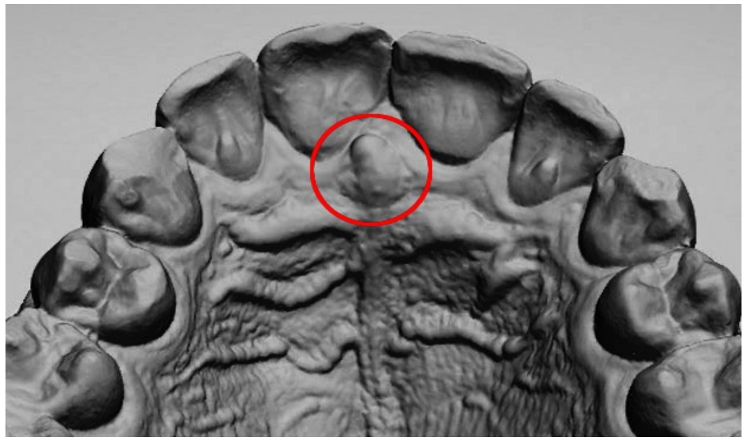


Figure 21 The Anatomical Position of the Incisive Papilla

4.2.1 Incisive Papilla as a Landmark

To ensure that incisive papilla is located in the right position each time we make other measurements, we need to standardize the right length and position to make so. The procedure started with taking the measurement for each 3D model for each papilla's length. Starting from the end gum part that located between both central incisors and ending at the bottom of the incisive papilla as showing in Figure 22.

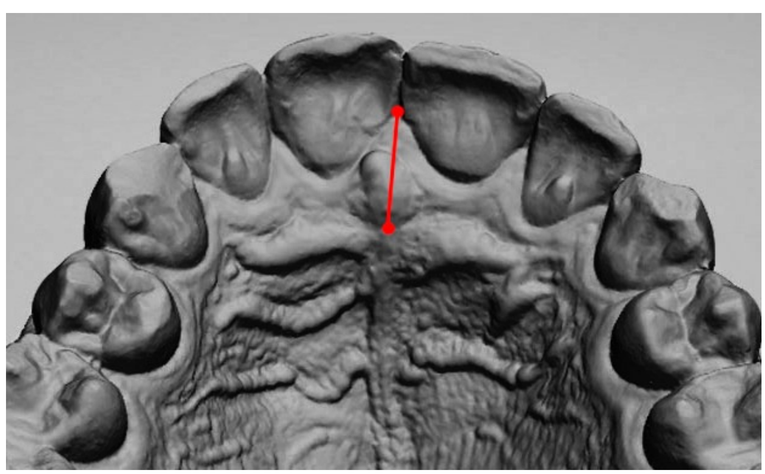


Figure 22 The Average Length of the Incisive Papilla

After doing the length measurements for all samples, the average length of the incisive papilla is divided by 2 in order to get the estimated middle point of each papilla to use it as a landmark for further measurements. Figure 23 is displaying the estimated point position where the incisive papilla is used as a landmark.

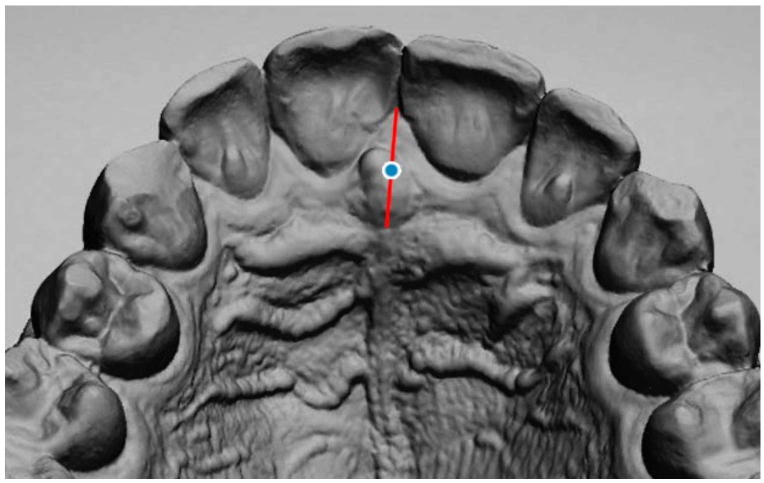


Figure 23 The Middle Point of the Incisive Papilla.

The next step after locating the middle point of the incisive papilla is to get the ratio distance between each palatal rugae and the incisive papilla, especially the first right rugae for identification purposes, and the rest rugae as well for gender and ethnicity differentiation.

The table 4.1 is showing the recorded length in (mm) for each incisive papilla in the data sample using Autodesk Maya Studio. Table 4.2 is the total of calculating all incisive papilla for all the 24 3D models. The average is added as well which was around 10(mm) in length. Table 4.3 is showing the estimated middle point where all measurements should start from which is the division of the average length by 2 = 5mm.

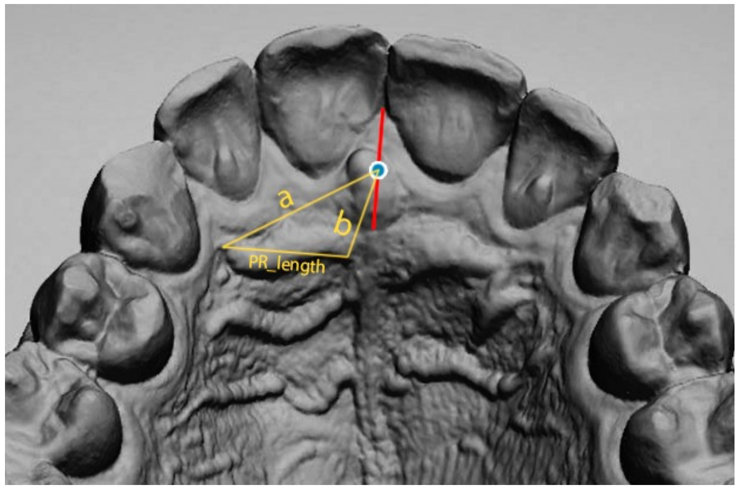


Figure 24 The usage of the Middle Point to Do the Palatal Rugae measurements.

Table 17 Incisive Papilla Length for all the 3D models.

Male		Female	
Case #	**Incisive Papilla Length (mm)**	**Case #**	**Incisive Papilla Length (mm)**
1	**11.9**	13	**10.7**
2	**11.1**	14	**8.9**
3	**9.4**	15	**11.5**
4	**10.3**	16	**10.1**
5	**11.2**	17	**10.7**
6	**7.9**	18	**8.5**
7	**7.9**	19	**11.6**
8	**9.8**	20	**8.5**
9	**9**	21	**9.3**
10	**11.2**	22	**10.5**
11	**10**	23	**10.1**
12	**10.7**	24	**10.1**
Total	**120.4**	Total	**120.5**

Table 18 Incisive Papilla Total Length as well as the Average.

Total	240.9
Average	10.0375

Table 19 The estimated Middle point for the incisive papilla.

Middle point	5.01875

No significant differentiation between the length of the incisive papilla between male and female. According to this study of 24 3D samples, the difference is 0.1mm in length. Therefore, it is possible to standardize the length of doing the further investigation, which is 5mm in length from the top point on the gum crossing the incisive papilla ending with the lateral point of the incisive papilla, since the landmark will be stable for other kind of measurements.

gendr * side Crosstabulation

Count

		side		
		L	R	Total
gendr	female	75	69	144
	male	65	64	129
Total		140	133	273

Figure 25 The distribution of the countable palatal rugae in both sides (R, L) for both genders.

4.2.2 Shape Classification

All palatal rugae were recorded and measured, using Lysell classification, from both genders. After analyzing the shapes in both genders, the total palatal rugae that recorded from all 24 subjects was 273 palatal rugae distributed between the following: Branched, Curved, Ring, Straight, and Wavy.

shape

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	branched	27	9.9	9.9	9.9
	curved	69	25.3	25.3	35.2
	ring	6	2.2	2.2	37.4
	straight	66	24.2	24.2	61.5
	wavy	105	38.5	38.5	100.0
	Total	273	100.0	100.0	

Figure 26 The Frequency Table of All Shapes Founded in both genders

The Wavy frequency was the largest where the frequency was 105 and took over 38.5% from the total percentage of the rest. Came after that the curved shape by a frequency of 69 and a 25.3% from the total proportion between other shapes. After that is the straight shape by a frequency of 66 and a percentage of 24.2%. The branched shape was 27 in frequency and 9.9% and the ring shape took the least frequency where it appears only 6 times in both genders and scored 2.2% from the total percentage.

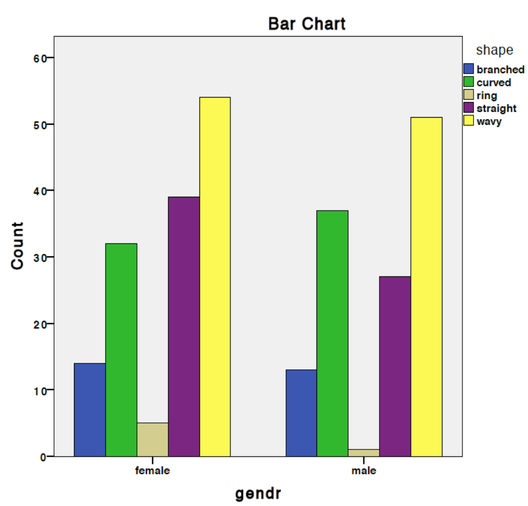


Figure 27 Plotting The Frequency Table of All Shapes Founded in both genders

Shape analysis with deferent ethnicity:

Anatomists have shown interest in the evolutionary development of PR, but surprisingly studies relating to it have been scarce in dental literature. A semi-quantitative method of analysis by Szilvassy & Hauser [54], based on an earlier method of Reuer [55] indicates the presence of inter-racial differences in PR and its pattern. Ethnic variation was also reported by Thomas C.J. based on Lysell classification. Inter and intra population analysis between Greeks (South Europeans) and South African (Swazi, Bantu) population suggested obvious ethnic differences by Hauser G *et al* [17]. The Swazi's have stronger and complex main (primary) rugae than the Greeks. There was an association observed between the primary rugae and the palatal size of this population.

The following table 4.4 is shown the ethnicity differentiation between the following ethnicity: Australian Aborigines, Australian Caucasian, Indians Madhya Predesh, Indians Kerala, Indians Mahara-shtra, Indians Karnataka, and Saudis (Aseer Region) which is the concluded number of palatal rugae from this study. Although the number of subject in this study is not as big as the others comparing it with the Australian Aborigines and the Australian Caucasian, but comparing the findings from this study with other number of subjects like the Indians Madhya Predesh and Indians Kerala shows some significant differentiation of total number between 24 samples which concluded 273 total of palatal rugae and 30 samples in both which concluded (150 and 153 palatal rugae).

Table 20 Ethnicity comparison of palatal rugae shapes Based on Lysell classification

		100	**220**	**30**	**30**	**50**	**50**	**24**
Ethnicity		Australian Aborigines	Australian Caucasian	Indians Madhya Predesh	Indians Kerala	Indians Mahar a-shtra	Indians Karnataka	Saudis (Aseer Region)
Shape	**Straight**	**34** *(3.6%)*	**176** *(15.2%)*	**38** *(25.3%)*	**25** *(16.3%)*	**154** *(31%)*	**116** *(23.8%)*	**66** (24.2 %)
	Curved	**221** *(23.2%)*	**298** *(25.8%)*	**35** *(23.3%)*	**39** *(25.4%)*	**212** *(42.7%)*	**108** *(22.1%)*	**69** (25.3 %)
	Wavy	**531** *(55.8%)*	**469** *(40.6%)*	**43** *(28.7%)*	**54** *(35.3%)*	**127** *(25.6%)*	**257** *(52.7%)*	**105** (38.5 %)
	Ring	**34** (3.6%)	**33** (2.9%)	**9** (6%)	**8** (5.2%)	**4** (0.8%)	**7** (1.4%)	**6** (2.2%)
	Unification	**132** *(13.9%)*	**180** *(15.6%)*	**25** *(16.7%)*	**27** *(17.6%)*	**-**	**-**	**27** (9.9%)
Total		**952** (100%)	**1156** (100%)	**150** (100%)	**153** (100%)	**370** (100%)	**488** (100%)	**273** (100%)

Ethnicity comparison of palatal rugae shapes Based on Lysell classification. Shwetha K. S et al [53] assessed the length, shape and unification of rugae in Mysorean (Indian) and Tibetan people. The Saudi (Aseer Region) population was added and compared.

Moreover, the same classifications were used in all ethnicity groups, which was Lysell classification. The only deferent thing between both conclusions is both Indians Madhya Pradesh and Indians Kerala samples were collected manually and measured using a regular ruler. Therefore, the missing palatal rugae were discarded based on Lysell where the primary rugae are the once that calculated.

This is shown that using the 3D models and doing the measurements by the Arch Length method in Autodesk Maya Studio calculated more rugae therefore, less bias of counting the primary rugae.

Shape analysis with new Classification:

To conclude all shapes that been recognized and analyzed in the 24 samples, the shapes are generally divided into to main categories: Simple and combined. The simple shapes are : Straight, Curved, Ring, and Wavy. The combined shapes are those who got two or more simple shapes merged together.

We start with the simple shapes by substituting the long name by (S, C, R, and W) is not enough to differentiate a rugae from the other. Therefore, the orientation of each rugae is put under consideration in this study. By using the orientation and concatenates it with the shortcuts (S, C, R, W) will ensure that the configured rugae is the right one. The next table 21 is shown the main shape orientation for the straight shape that palatal rugae could have.

Straight Shape:

Table 21 The Straight Shape Classification.

Straight [S]	H	V	fw	bw
				

Table 22 The Straight Shape Substitution.

Straight [S]	H	V	fw	bw
	Horizontal	Vertical	Forward	Backward

The straight shape appeared in the recorded 3D models 66 times (24.2%) of the total number of the 273 palatal rugae. Rather than use it and count it as a single unit by saying (straight), we now increase the probability of the shape by quarter. From another hand, the usage of the palatal rugae is now substituted by these probabilities: [SH, SV, Sfw, Sbw]. Also, the side of the palate where the palatal rugae will appears in will increase the probability as well by 2. An example is the following: for the right side of the palate [RSH, RSV, RSfw, RSbw] and for the left side of the palate [LSH, LSV, LSfw, LSbw].

Table 23 The before and after count of straight rugaes using the old classification and my classification.

Number of Calculating Straight rugae (Before)		Number of Calculating Straight rugae (After)		
Shape	Count	Shape		Count
Straight (S)	66	R	RSH	7
			RSV	1
			RSfw	12
			RSbw	9
		L	LSH	12
			LSV	0
			LSfw	13
			LSbw	12

Curved Shape:

Table 24 The Curved Shape Classification.

Curved [C]	U	D	R	L	DR	DL	UR	UL
								

Table 25 The Curved Shape substitution for the orientation.

Curved [C]	U	D	R	L	DR	DL	UR	UL
	Up	Down	Right	Left	Down-Right	Down-Left	Up-Right	Up-Left

The curved shape appeared in the recorded 3D models 69 times (25.3%) of the total number of the 273 palatal rugae. Rather than use it and count it as a single unit by saying (curved), we now increase the probability of the shape by 8. From another hand, the usage of the palatal rugae is now substituted by these probabilities: [CU, CD, CR, CL, CDR, CDL, CUR, and CUL].

Also, the side of the palate where the palatal rugae will appears in will increase the probability as well by 2. An example is the following: for the right side of the palate [RCU, RCD, RCR, RCL, RCDR, RCDL, RCUR, and RCUL] and for the left side of the palate [LCU, LCD, LCR, LCL, LCDR, LCDL, LCUR, and LCUL].

Table 26 The before and after count of curved rugaes using the old classification and my classification.

Number of Calculating Curved rugae (Before)		Number of Calculating Curved rugae (After)		
Shape	Count	Shape		Count
Curved (C)	69	R	RCU	7
			RCD	1
			RCR	12
			RCL	9
			RCDR	12
			RCDL	0
			RCUR	13
			RCUL	12
		L	LCU	7
			RCD	1
			LCR	12
			LCL	9
			LCDR	12
			LCDL	0
			LCUR	13
			LCUL	12

Ring Shape:

Even though the ring shape appeared in the recorded 3D models 6 times (2.2%) of the total number of the 273 palatal rugae, this classification can help future investigators to analyze the ring shape in depth especially for larger collected samples. With the ring shape classification, rather than use it and count it as a single unit by saying (ring), we now increase the probability of the shape by

16. From another hand, the usage of the palatal rugae is now substituted by these probabilities: [RU, RD, RR, RL, RDR, RDL, RUR, RUL, RH, RV, Rfw, Rbw].

Also, the side of the palate where the palatal rugae will appears in will increase the probability as well by 2. An example is the following: for the right side of the palate [RRU, RRD, RRR, RRL, RRDR, RRDL, RRUR, RRUL, RRH, RRV, RRfw, RRbw] and for the left side of the palate [LRU, LRD, LRR, LRL, LRDR, LRDL, LRUR, LRUL, LRH, LRV, LRfw, LRbw].

Table 27 The Ring Shape Classification.

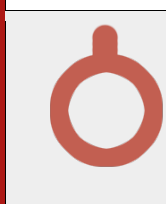
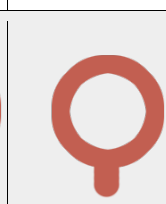
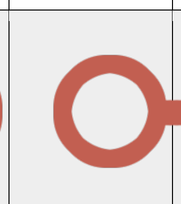
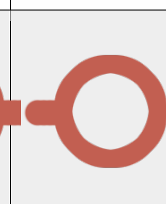
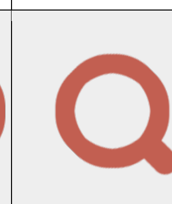
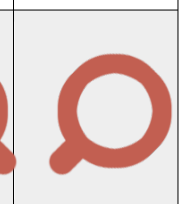
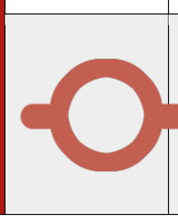
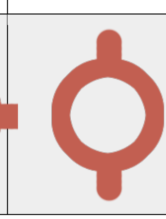
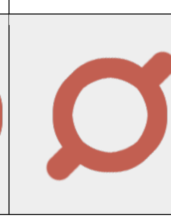
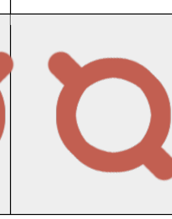
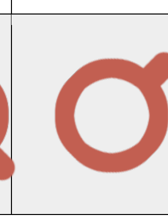
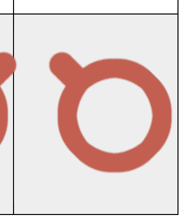
Ring [R]	U	D	R	L	DR	DL
						
	H	V	fw	bw	UR	UL
						

Table 28 The Ring Shape substitution for the oreintation.

Ring [R]	U	D	R	L	DR	DL
	Up	Down	Right	Left	Down-Right	Down-Left
	H	V	fw	bw	UR	UL
	Horizantal	Virtical	Forward	Backward	Up-Right	Up-Left

Table 29 The before and after count of ring rugaes using the old classification and my classification.

Number of Calculating Ring rugae (Before)		Number of Calculating Ring rugae (After)		
Shape	Count	Shape		Count
Ring (R)	6	R	RRU	0
			RRD	0
			RRR	0
			RRL	1
			RRDR	1
			RRDL	0
			RRUR	0
			RRUL	0
			RRH	0
			RRV	0
			RRfw	0
			RRbw	1
		L	LRU	0
			LRD	0
			LRR	0
			LRL	0
			LRDR	0
			LRDL	2
			LRUR	0
			LRUL	0
			LRH	0
			LRV	0
			LRfw	1
			LRbw	0

Wavy Shape:

Wavy [W]	**Each wavy shape consist of the following Four elements:**
	1) Starting point. 2) Crests ***(Cn)***. 3) Valleys ***(Vn)***. 4) Ending Points.

Table 30 The Wavy Shape Classification.

The wavy shape appeared in the recorded 3D models 105 times (38.5%) of the total number of the 273 palatal rugae, which were the biggest counted rugae among all other shapes. This classification of the wavy shape is a bet different from the previous once because the nature of ups and downs shapes that the wavy shape has. Thus, different approach is apply to handle it shape for identifies it from the combined shape. With the wavy shape classification, rather than use it and count it as a single unit by saying (wavy), we now increases the probability of the shape by calculating the four elements that the shape has. The elements are: Starting point, Crests ***(Cn),*** Valleys ***(Vn)***, and Ending Points. From another hand, the wavy shape of the palatal rugae is now substituted by these probabilities of the following:

[*Side(R:L) | W | Staring_Point | Ending_Point | Number_of_Crests(Cn) | Number_of_Valleys(Vn)*]

Where ***Side(R: L)*** is the location where the ring shape is located, either in the right side or in the left side. ***W***, is the substitution of the word "wavy". ***Starting_Point***, is the beginning left side of the wavy palatal rugae where the shape recognition will start from, either [Up or Down] (U, D). ***Ending_Point***, is the beginning left side of the wavy palatal rugae where the shape recognition will start from, either [Up or Down] (U, D). ***Number_of_Crests (Cn)*** is the calculation of how many times the crests appears in this wavy shape. ***Number_of_Valleys (Vn)***, is the calculation of how many times the valleys appears in that wavy shape. Here is an example of how the result of conducting a wavy shape in this classification.

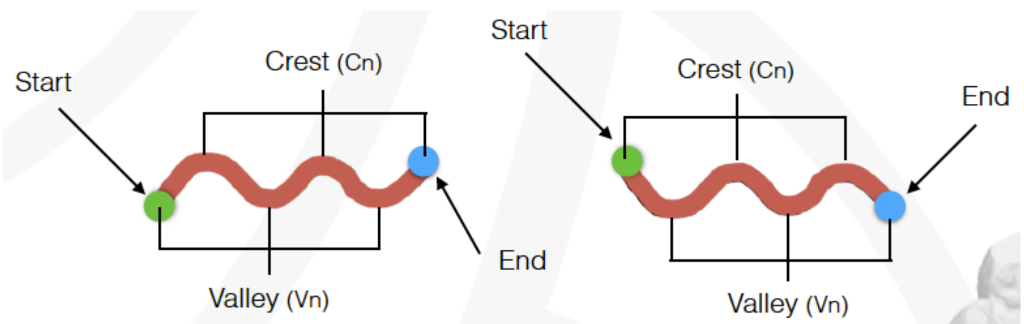


Figure 28 Extracting the Wavy shape based on orientation.

[Side(R or L)] [W] [D] [U] [Cn(3)] [Vn(3)] | [side(R or L)] [W] [U] [D] [Cn(3)] [Vn(3)]

In Figure 28, the left side wavy shape will be substituted by: [**RWDU33**] for the right side. And [**LWUD33**] for the left side. The following figure is an example of what kind of results we can get using this classification.

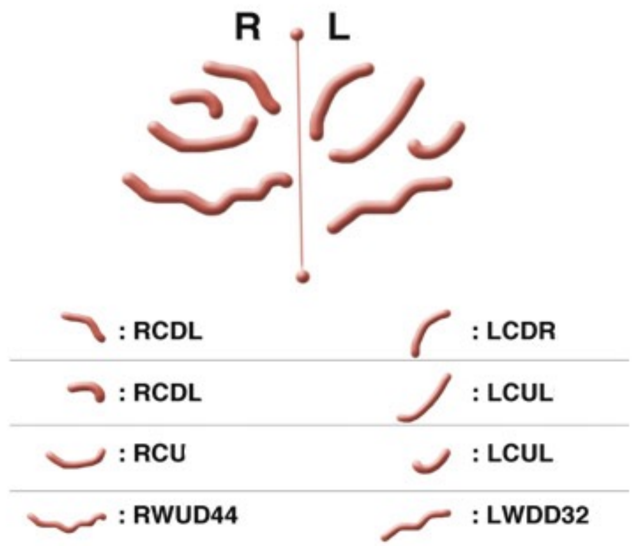


Figure 29 Simple shape pattern extraction

As we mentioned before, the shapes are generally divided into to main categories: **Simple** and **combined**. The simple shapes are: Straight, Curved, Ring, and Wavy. The combined shapes are those who got two or more simple shapes merged together. The combined shapes are generally same substitution of the simple shapes separated by the dash character (-). Figure 30 Illustrating that in the first right curvy rugae:

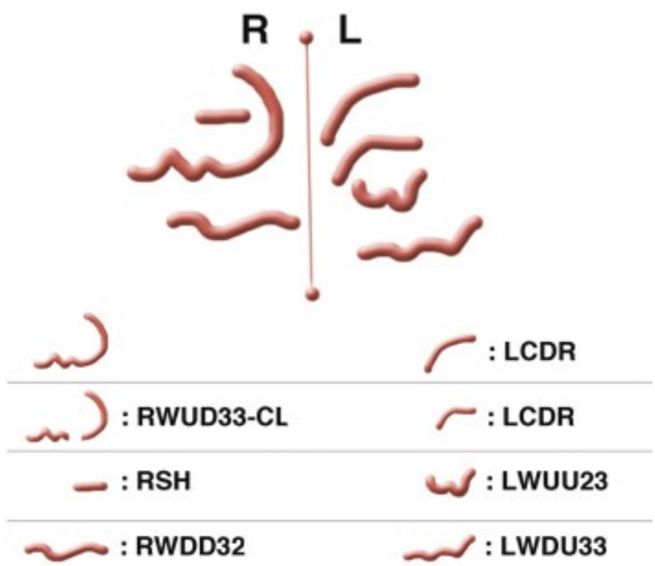


Figure 30 Combined shape pattern extraction

4.2.3 First Right Palatal Rugae Shape Analysis

All palatal rugae shapes for the first right palatal rugae were recorded and measured, using Lysell classification, for both genders. After analyzing the shapes in both genders, the total palatal rugae that recorded from all 24 subjects was 12 palatal rugae collected for the males as well as 12 for the females. Distributed between the following: Branched, Curved, Ring, Straight, and Wavy. The following table is shown the ruga shapes distribution between all 24 subjects.

Table 31 The First Right Rugae Shape in all the 3D models.

Male		Female	
Case #	First Right PR Shape	Case #	First Right PR Shape
1	**Curved**	1	**Brunched**
2	**Straight**	2	**Curved**
3	**Straight**	3	**Brunched**

Male		Female	
Case #	First Right PR Shape	Case #	First Right PR Shape
4	Wavy	4	Curved
5	Curved	5	Straight
6	Brunched	6	Brunched
7	Curved	7	Curved
8	Curved	8	Brunched
9	Brunched	9	Curved
10	Wavy	10	Curved
11	Straight	11	Brunched
12	Brunched	12	Straight

Table 32 The Count of the First Right Rugae Shape in all the 3D models.

	Male	Female
Shapes Appears in the First Right PR	Number of Appearance	Number of Appearance
Straight	3	2
Curved	4	5
Wavy	2	0
Ring	0	0
Brunched	3	5
Total	12	12

It is important to concentrate on these particular rugae for two reasons. First, we are investigating the palatal rugae similarities and differences down to the smallest level of the palatal rugae which is the single ridge. Therefore, based on that level of comparison, new ways to implement and create identification is possible without the need of collecting the whole palatal rugae shapes and measurements. Thus, a significant save of time and efforts. Table 31 and table 32 are showing descriptive statistics about the shapes that appears in the first right palatal rugae (FRPR) that will be use later for the sake of identification extraction. It is shown that ring shape is absent in both genders. Wavy shapes from another hand, appears in the male group twice, unlike the female group where it was absent.

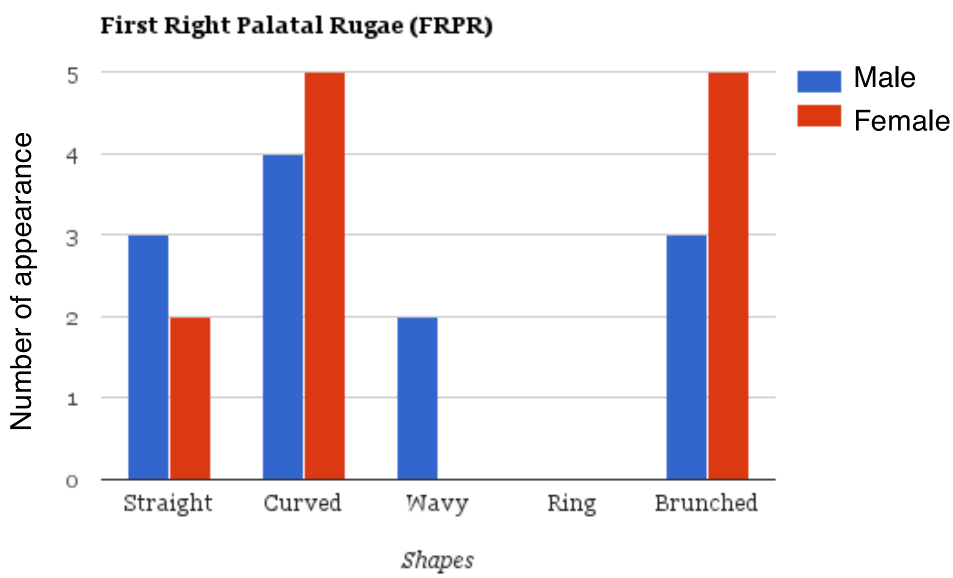


Figure 31 First Right palatal rugae Shape distribution

4.3 Measurement Analysis

Measurement analysis is the main reason of collecting all palatal rugae samples in 3D. The accuracy part of this study is important. Based on Lysell classification, each rugae have its own length: primary (5mm and more), secondary (between 3-5mm), and fragmentary (between 2-3mm). Less than 2mm are disregarded. There are big differences in the 3D world of measuring by using a regular ruler to calculate the distance between two points [A and B] and the actual length, which can be extracted by ArchLen() method. The natural shape of the human palate is curved and has a dome shape. Therefore, the palatal rugae are arranged within that curve. So, it is not valid to calculate the distance between two curved points using a simple ruler. Figure 32 shows an important step to make sure that all 3D samples will have the same dimensions in reality. Accordingly, a collection of both (manual and 3D) measurements will be collected and compared.

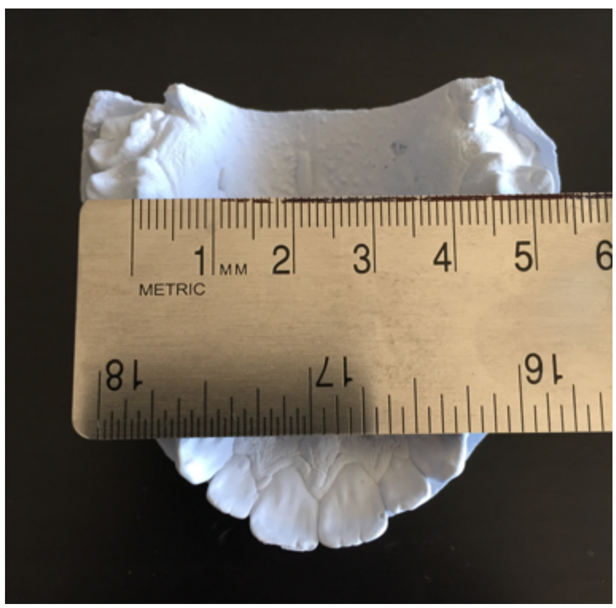


Figure 32 Manual measurement using ruler

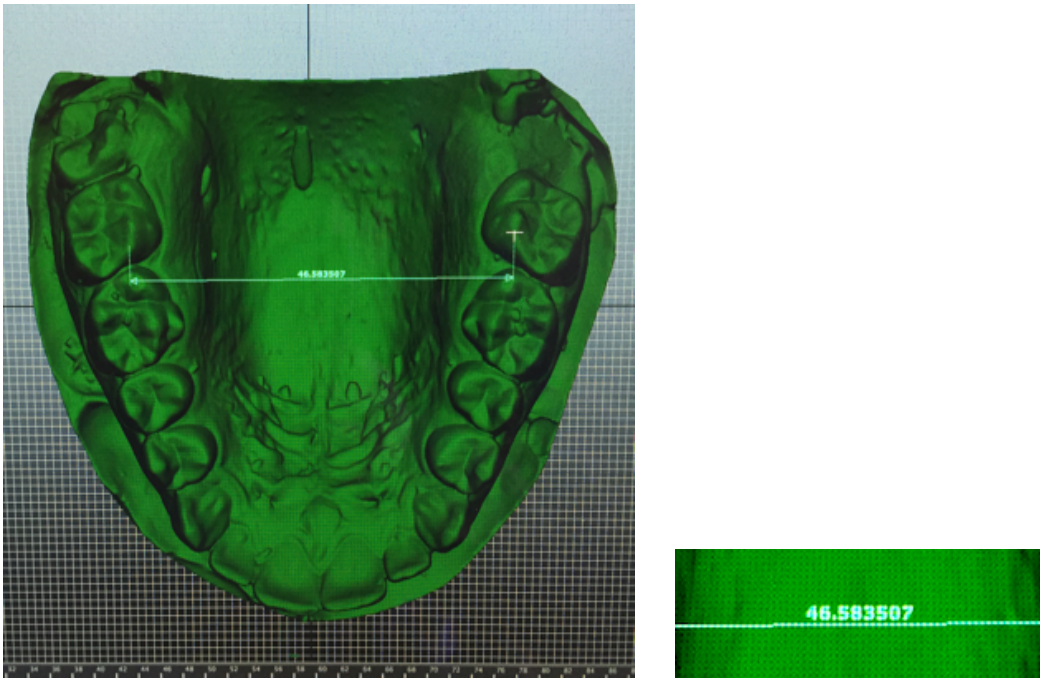


Figure 33 Ruler measurement simulating in the 3D world.

By starting with regular ruler, we make sure that we are measuring the 3D model in an accurate way. The previous figures show that accuracy of using the digital ruler vs. the 3D ruler. Moreover, to solve the problem of calculating the curved shapes, I used a method called “ArchLen ( )” that follows any curve and give the actual length. In conclusion, a better way to measure the palatal rugae electronically, as well as adding more primary rugae to the calculation rather than excluding it based in Lysell classification as shown in Table 33.

Rugae type	Measurement (mm)
Primary	5 and more
Secondary	3 - 5
Fragmentary	2 -3

Table 33 Lysell classified the palatal rugae depending on the rugae length in (mm).

In Figure 34 the major differentiation between using the straight line measurement tool, like a ruler, comparing with the ArchLen() method in Autodesk Maya Studio that get the accurate measurement for the curved shapes.

Figure 34 Comparing the straight length with the wavy length

The wavy shape length by using a ruler *(green)*: 22.47mm The wavy shape real length by using ArchLen() method *(gray)*: 30.6mm There is a big margin of error where almost 8mm.

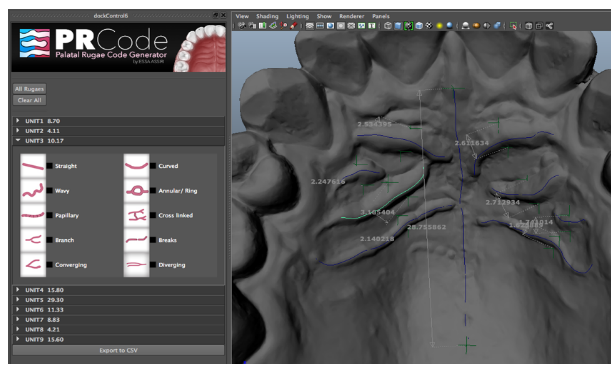


Figure 35 Comparing the straight length with the wavy length

4.3.1 Measurement Classification

All palatal rugae were recorded and measured, using Lysell classification to include and rugae is bigger than 5mm to be a primary rugae, from both genders. After analyzing the measurements in both genders, the total palatal rugae that recorded from all 24 subjects was a 24 table that have all measurements about every rugae inside.

The following tables are the 24 samples that been tested through this study. 24 cases have been displaced with a descriptive data about each case measurement for the palatal rugae with respect of the following:

- number of rugae;
- the rugae side (R) for right side of the palate, and (L) for the left side of the palate;
- the distance in (mm) between the incisive papilla and the beginning of the rugae (Papilla_a);
- the distance in (mm) between the incisive papilla and the ending part of the rugae (Papilla_b);
- the radio in (mm) between Papilla_a and Papilla_b (Ratio);
- the distance in (mm) between the Median Raphe and the palatal rugae (Displacement); Table 34 All Measurements for Palatal Rugae Case : 1

CASE No. 1								
N	Side	Papilla_a (mm)	Papilla_b (mm)	Ratio (mm)	Displaceme nt (mm)	Thickne ss (mm)	Shape	Length (mm)
1	R	12.1	5.3	2.28	1.5	2	curved	10.1
2	R	13	9.6	1.35	1.1	1.7	wavy	12.2
3	R	19.5	15.9	1.23	1.4	1.2	curved	15.1
4	R	22.4	19.8	1.13	10.9	0.9	straight	4.1
5	R	27.4	18.4	1.49	8.4	0.8	wavy	10.2

6	R	21.1	20.2	1.04	4.8	0.6	curved	5.1
7	L	12	5.5	2.18	2	1.7	curved	10.0
8	L	12.3	9.8	1.26	1.2	1.6	branched	11.2
9	L	14.9	12.8	1.16	8.1	1	straight	2.3
10	L	13.7	13.7	1.00	5.8	0.7	straight	1.5
11	L	16.1	16.3	0.99	2.5	1.8	wavy	11.1
12	L	18.8	17.3	1.09	11.4	0.7	straight	3.0
13	L	21.3	20.2	1.05	1.5	0.9	wavy	14.9

The previous table is just a sample of the way of creating the dataset for all 3D cases that this study includes. The following is the overall measurements differentiations and similarities between using the ArchLen () method and the straight line ruler measurement tool.

Table 35 Total Length of Palatal Rugae using: 1- ArchLen() 2- Ruler.

Measurement Tool	Total Length of Palatal Rugae in (mm)
3D measurement tool : ArchLen()	2,739.3
Manual technique tool : Ruler	2,175.5

Summary of the total number of ArchLength and Distance for all samples

Summary	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Sample 8	TOTAL
Total ArchLength (3D)	100.81	123.57	121.27	84.38	128.7	113.6	117.28	124.02	***913.63***
Total Distance (Rular)	87.48	89.33	97.72	70.63	106.45	85.95	92.11	95.24	***724.91***
Total Thikness	13.83	21.12	15.46	13.96	16.47	18.36	17.61	19.18	***135.99***
Right Rugae	**6**	**4**	**4**	**6**	**6**	**8**	**5**	**6**	***45***
Left Rugae	**4**	**5**	**6**	**8**	**6**	**4**	**4**	**7**	***44***
Total Number of PRon Both Sides:	**10**	**9**	**10**	**14**	**12**	**12**	**9**	**13**	89
Mean	**10.081**	**13.73**	**10.88**	**8.64**	**10.72**	**9.46**	**13.03**	**9.54**	
Total ArchLength (3D):	**913.63**								
Total Distance	**724.91**		**RR avg.**	**5.625**					
Total Thinkness:	**135.99**		**LR avg.**	**5.5**					
Total number of PR:	**89**		**All Avg.**	**11.125**					
3D Average:	114.20375								
Rular Average:	90.61375								
3D Standar Diviation	14.74950356								
Rular Stander Diviation	10.40258064								

Figure 36 Summary of the ArchLen() measurements in female samples.

4.3.2 First Right Palatal Rugae Measurement Analysis

The first right palatal rugae as we mentioned before is a critical rugae because its the one that will be used to extract the biometrics based identification for the subjects using the palatal rugae. In this specific rugae, three steps of calculating the palatal rugae took it place. First, we calculate the length between the incisive papilla and the begging of the palatal rugae. Second, we calculate the distance between the incisive papilla and the end of the rugae. Finally, we calculate the length of the rugae itself using the ArchLen() method for the actual length of the rugae. All in all, that will increase the amount of probability of having a unique identification when we generate it.

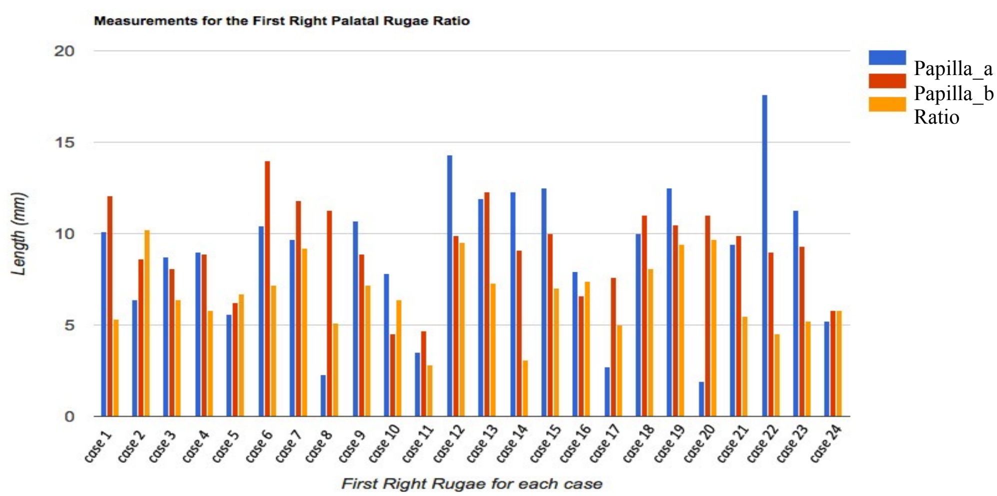


Figure 37 Summary of the ArchLen() measurements in 24 cases.

The following table 4.19, is showing the length of the first right palatal rugae for each subject with respect of gender.

Table 36 The First Right Rugae Measurement in all the 3D models in (mm).

Male		Female	
Case #	Length in (mm)	Case #	Length in (mm)
1	**10.1**	1	**11.9**
2	**6.4**	2	**12.3**
3	**8.7**	3	**12.5**
4	**9.0**	4	**7.9**
5	**5.6**	5	**2.7**
6	**10.4**	6	**10.0**
7	**9.7**	7	**12.5**
8	**2.3**	8	**1.9**
9	**10.7**	9	**9.4**
10	**7.8**	10	**17.6**
11	**3.5**	11	**11.3**
12	**14.3**	12	**5.2**

Table 37 The Beginning of The First Right Rugae and the Incisive Papilla Measurement in all the 3D models in (mm).

Male		Female	
Case #	Length of papilla_a in (mm)	Case #	Length of papilla_a in (mm)
1	**12.1**	1	**12.3**
2	**8.6**	2	**9.1**
3	**8.1**	3	**10.0**
4	**8.9**	4	**6.6**
5	**6.2**	5	**7.6**
6	**14.0**	6	**11.0**
7	**11.8**	7	**10.5**

Male		Female	
Case #	Length of papilla_a in (mm)	Case #	Length of papilla_a in (mm)
8	**11.3**	8	**11.0**
9	**8.9**	9	**9.9**
10	**4.5**	10	**9.0**
11	**4.7**	11	**9.3**
12	**9.9**	12	**5.8**

Male		Female	
Case #	Length of papilla_b in (mm)	Case #	Length of papilla_b in (mm)
1	**5.3**	1	**7.3**
2	**10.2**	2	**3.1**
3	**6.4**	3	**7.0**
4	**5.8**	4	**7.4**
5	**6.7**	5	**5.0**
6	**7.2**	6	**8.1**
7	**9.2**	7	**9.4**
8	**5.1**	8	**9.7**
9	**7.2**	9	**5.5**
10	**6.4**	10	**4.5**
11	**2.8**	11	**5.2**
12	**9.5**	12	**5.8**

Table 38 The Ending of The First Right Rugae and the Incisive Papilla Measurement in all the 3D models in (mm).

An overall calculation for the first right palatal rugae

Table 39 Identification Extracted Measurements Using the First Right Palatal Rugae

No	**Length** *(mm)*	**papilla_a** *(mm)*	**papilla_b** *(mm)*	**papilla_c** *(mm)*
1	**10.1**	**12.1**	**5.3**	**7.4**
2	**6.4**	**8.6**	**10.2**	**11.6**
3	**8.7**	**8.1**	**6.4**	**5.3**
4	**9**	**8.9**	**5.8**	**4.4**
5	**5.6**	**6.2**	**6.7**	**5.9**
6	**10.4**	**14**	**7.2**	**9.8**
7	**9.7**	**11.8**	**9.2**	**10.1**
8	**2.3**	**11.3**	**5.1**	**7.8**
9	**10.7**	**8.9**	**7.2**	**6.8**
10	**7.8**	**4.5**	**6.4**	**5.2**
11	**3.5**	**4.7**	**2.8**	**5.4**
12	**14.3**	**9.9**	**9.5**	**9.2**
13	**11.9**	**12.3**	**7.3**	**9.3**
14	**12.3**	**9.1**	**3.1**	**5.4**
15	**12.5**	**10**	**7**	**3.9**
16	**7.9**	**6.6**	**7.4**	**5.5**
17	**2.7**	**7.6**	**5**	**6.3**
18	**10**	**11**	**8.1**	**7.3**
19	**12.5**	**10.5**	**9.4**	**8.4**
20	**1.9**	**11**	**9.7**	**8.8**
21	**9.4**	**9.9**	**5.5**	**5.3**
22	**17.6**	**9**	**4.5**	**12.1**
23	**11.3**	**9.3**	**5.2**	**7.2**
24	**5.2**	**5.8**	**5.8**	**5.1**

4.3.3 Pattern of the PR Identification

Shape differences were assessed while doing the pattern of the biometrics based identification for the First Right palatal rugae. The main idea was to stabilize the landmark for the incisive papilla and use it as a starting point for all measurements and that was done by calculating the average length of all papilla and then divided by 2 to get the middle point. From that middle point we can measure the length from the incisive papilla to the starting point of the rugae and from the papilla to the end point of the rugae. The next figure is shown the triangular shape that represents the distances from the incisive papilla back and forth. The rule of thumb to extract identification is to have a pattern of probabilities that create sequences for the palatal rugae. However, using all palatal rugae is not efficient since the first right palatal rugae could create a huge amount of probabilities without the need of the rest of palatal rugae.

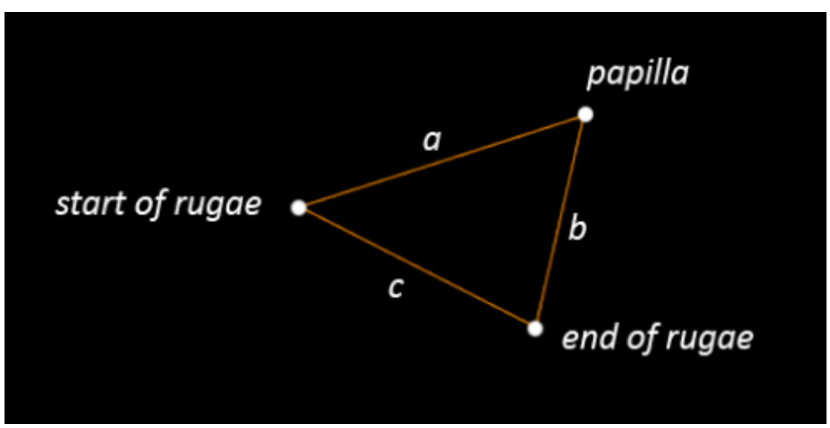


Figure 38 An Abstraction of the Concluded Shape Recognition of the First Right Palatal Rugae

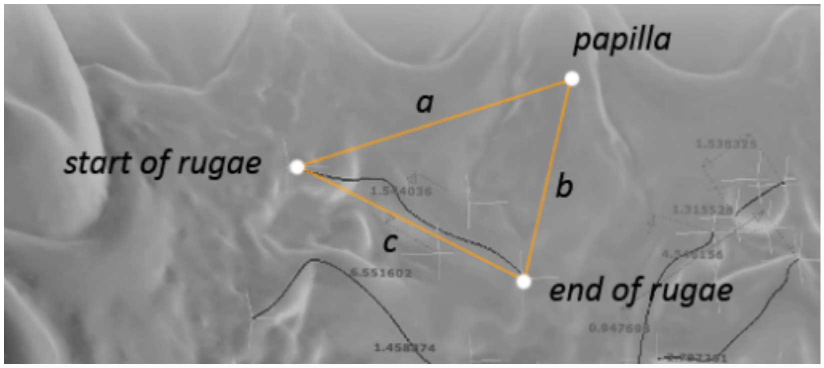


Figure 39 the Concluded Shape Recognition of the First Right Palatal Rugae

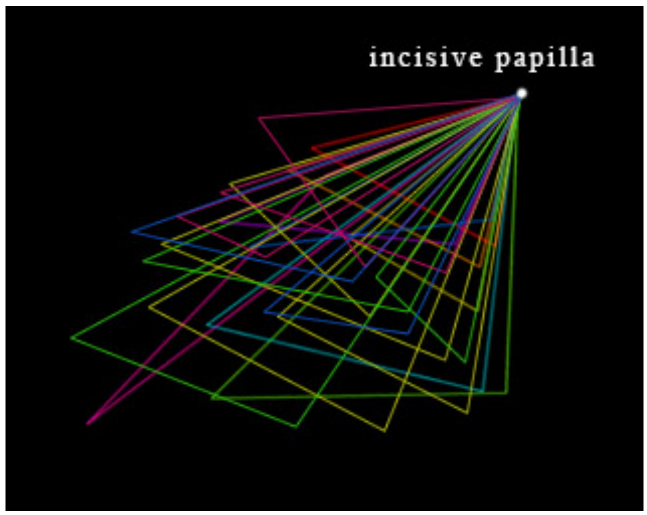


Figure 40 The Concluded Shape Recognition of the First Right Palatal Rugae for all 24 Samples

The shapes in Figure 40 showing the representation for all samples collected in this study. The result is a complex shape of triangles that different from each other. Those shapes represent the randomness of the identification shape that this study is generating by using the first right palatal rugae.

4.5 Identification Generator:

To generate the palatal rugae biometrics based identification, five elements needed to concatenate with each other in order to create a sequence of the PR identification. The five elements are shown in Table 40 where the following indexes are determined:

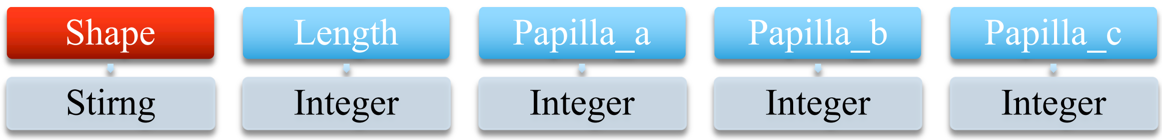


Figure 41 palatal rugae pattern structure.

Table 40 The Five Elements of Generating the Identification Code

Shape	Length (mm)	papilla_a (mm)	papilla_b (mm)	papilla_c (mm)
RCL	10.1	12.1	5.3	7.4
RSH	6.4	8.6	10.2	11.6
RWUD23	9.0	8.9	5.8	4.4
RSH	8.7	8.1	6.4	5.3
RCDL	5.6	6.2	6.7	5.9
RCR-SH	10.4	14.0	7.2	9.8
RCD	9.7	11.8	9.2	10.1
RCDR	2.3	11.3	5.1	7.8
RCL-WDD22	10.7	8.9	7.2	6.8
WUU33	7.8	4.5	6.4	5.2
RSfw	3.5	4.7	2.8	5.4
RSbw-WUD32	14.3	9.9	9.5	9.2
RSH-CDR	11.9	12.3	7.3	9.3
RCR	12.3	9.1	3.1	5.4
RCL-WUD32	12.5	10.0	7.0	3.9
RCDR	7.9	6.6	7.4	5.5
RSfw	2.7	7.6	5.0	6.3
RWUD33-CL	10.0	11.0	8.1	7.3
RCLD	12.5	10.5	9.4	8.4
RSfw-CUR	1.9	11.0	9.7	8.8
RCL	9.4	9.9	5.5	5.3
RCUR	17.6	9.0	4.5	12.1
RWUD32-Sfw	11.3	9.3	5.2	7.2
RSH	5.2	5.8	5.8	5.1

Measurement analysis is the main reason of collecting all palatal rugae samples in 3D. The accuracy part of this study is important. Based on Lysell classification, each rugae have its own length: primary (5mm and more), secondary (between 3-5mm), and fragmentary (between 2-3mm). Less than 2mm are disregarded. There are big differences in the 3D world of measuring by using a regular ruler to calculate the distance between two points [A and B] and the actual length, which can be extracted by ArchLen() method. The natural shape of the human palate is curved and have a dome shape. Therefore, a biometric identification based analysis of incisive papilla was applied to all 24 samples to extract all identification shown in Figure 42.

MALE	
Sampl	PR Code (Identification)
1	RCL 10.1 12.1 5.3 7.4
2	RSH 6.4 8.6 10.2 11.6
3	RSH 8.7 8.1 6.4 5.3
4	RWUD23 9.0 8.9 5.8 4.4
5	RCDL 5.6 6.2 6.7 5.9
6	RCR-SH 10.4 14.0 7.2 9.8
7	RCD 9.7 11.8 9.2 10.1
8	RCDR 2.3 11.3 5.1 7.8
9	RCL-WDD22 10.7 8.9 7.2 6.8
10	WUU33 7.8 4.5 6.4 5.2
11	RSfw 3.5 4.7 2.8 5.4
12	RSbw-WUD32 14.3 9.9 9.5 9.2

FEMALE	
Sample	PR Code (Identification)
13	RSH-CDR 11.9 12.3 7.3 9.3
14	RCR 12.3 9.1 3.1 5.4
15	RCL-WUD32 12.5 10.0 7.0 3.9
16	RCDR 7.9 6.6 7.4 5.5
17	RSfw 2.7 7.6 5.0 6.3
18	RWUD33-CL 10.0 11.0 8.1 7.3
19	RCLD 12.5 10.5 9.4 8.4
20	RSfw-CUR 1.9 11.0 9.7 8.8
21	RCL 9.4 9.9 5.5 5.3
22	RCUR 17.6 9.0 4.5 12.1
23	RWUD23-Sfw 11.3 9.3 5.2 7.2
24	RSH 5.2 5.8 5.8 5.1

Figure 42 The way of Extracting the Identification using First Right Palatal Rugae as will as a list of all 24 samples identification.

Chapter 5: DISCUSSION

In this study the estimation of the uniqueness of the PR pattern in the study population will be carried out in three ways:

5.1 Uniqueness of PR as a Biometrics

All the PR-Code of the study population entered in Microsoft Excel 2015 software. Each PRC checked with the remaining PRC's for a possible match using the '*Countifs*' formula:

COUNTIFS ([criteria_range1, criteria1], [criteria_range2, criteria2], …)

If no match is found, the codes of the study population will be considered unique. As a result; The ***Countifs*** result was 0. This means there was 0 similarities between the identification extracted from the palatal rugae extraction. Allowing for bigger probability if the identification used more than one palatal rugae to extract the identification.

5.2 Uniqueness of PR-Shape Pattern

All the palatal rugae shapes tested in order to see the probability of having a chance of matching with other pattern. No match found, it considered unique from one triangle to the other.

5.3 Accuracy of palatal pattern measurement in 3D

All the 3D objects landmarks measured using ArchLen () measurement tool in order to get the actual length of each rugae.

It is possible to create a new classification scheme for the purpose of extracting the palatal rugae identification. Palatal rugae pattern have the same criteria that other biometrics based identification have; therefor, palatal rugae is considered as one of the multimodal biometrics tools in the field of forensic odontology.

The advantage of using 3D image of the palatal rugae is the accurate measurement results. The multi-shapes abstraction of the palatal rugae makes it easier to handle and analyze the auto-shape-detection in the future.

In this study, the nature of palatal rugae enrollment and the nature of palatal rugae matching were studded. It is possible that the palatal rugae data obtained during biometric enrollment may be used in ways for which the enrolled individual has not consented. That is possible in the dental clinics by doing an intra-oral scan for the upper part of the palate. Therefore, save the identification information in a central database that hold all palatal rugae biometrics based identification sequences and patterns. The process of enrollment goes through quality check and features extraction phases and finally to the database. The verification phase on other hand, extract the features first and then match (only one match) the inputs with the central database and see if there is a match or not. Finally, as a part of the identification extraction, the third phase is the identification phase, where the inputted biometrics based identification is matched with multiple number of other identification in order to see if there is any match between the input and the central database. Therefore, returns a flag of (yes or no) finding for the identification.

Also in this study, the establishment of the incisive papilla as a land mark for palatal rugae was studded. As a landmark, we need to ensure that incisive papilla is located in the right position each time we make other measurements that is why we standardized the right length and position to make so. The procedure started with taking the measurement for each 3D model for each papilla's length. Starting from the end gum part that located between both central incisors and ending at the bottom of the incisive papilla. The average length was taken from the whole samples. Finally divided by 2 to get the middle point where other measurements took their places for extracting the identification.

The performance of palatal rugae biometrics compared with other types of biometrics showed it benefits when it comes to big traumas. The extraordinary position of the palatal rugae makes it excellent biometrics based identification where it covers by other facial parts that protect it from exposed environmental challenges. Moreover, the field of biometrics based identification, classifications and methodologies are quite deferent from one researcher to the other. Moreover, in the field of rugoscopy, the main concentration was about the statistical outcomes that investigators got from the number of the rugae that investigated in one group and compare it and another group.

However, The main idea behind doing this study is to create a model and workflow of measuring the biometrical characteristics of the palatal rugae by using the modern technologies that are exists already in the field of dentistry such as the intra-oral scan to get a 3D model replica of the upper jaw as well as supporting the incomes with algorithms and functions from the field of computer science that could come with better and more accurate results as an outcomes in action for the field of the forensic odontology. Thus, all criteria of biometrics will be fulfilled in order to concede the palatal rugae recognition as one of the biometrics technologies.

The aim of this study is to examine the biometrics based characteristics for the palatal rugae patterns of Saudi adult population sample and use it as a biometrics based identification by using a (3D) three dimensional replica of the upper jaw of the participants. Also, to validate the accuracy of the rugae measurements through software and programming languages such as Autodesk Maya studio with the support of Python programming language. Moreover, to evaluate the quality of inserting and retrieving that information by translating the three dimensional coordinates into a numeric output that will be reuse to represent the patient's identification for the sake of using it as a new way to do the filing system in King Khalid University, Abha, Saudi Arabia.

Objectives:

- To study the biometrics characteristics of the palatal rugae.
- To study the morphology of the palatal rugae by using three dimensional (3D) software in a sample of Saudi's population for identification purposes.

- To determine if there is a gender differentiation in the palatal rugae patterns in Saudi's population.

- To compare the ethnicity of the findings with the results published in other literatures.

Hypothesis

- There is an approach to use the palatal rugae as identification based biometrics.
- There is a new methodology of establishing an identification based matrices for the subjects based on the palatal rugae based on measurement.
- There is a new methodology of establishing an identification based matrices for the subjects based on the palatal rugae based on shape.
- There is a unique pattern for each subject that could be used as identification based biometrics.
- There are measurement differences in the palatal rugae pattern between the 3D model and the stone cast.

- There is a possibility to use the first right rugae to establish identification without the need of the rest of the rugae.

- There are 3D shape differences in the palatal rugae pattern among Saudi population.

- There are 3D size differences in the palatal rugae pattern among Saudi population.
- There are biometrical characteristics that allow the palatal rugae to be a promising tool in forensic odontology.

5.4 Conclusions

In this section, the conclusions drawn from the study in relation to each of the research aims are presented.

First aim

To study the morphology of the palatal rugae by using three dimensional (3D) software in a sample of Saudi's population for identification purposes

The null hypothesis of the measurements using the three dimensional tools was about having no differences in length we used the ArchLen () method over the regular ruler.

The null hypothesis was rejected and the related conclusion drawn from the study was: There is a big margin of error when we use the regular ruler for the purpose of measurements for the palatal rugae. Therefore, the usage of the three dimensional distance tool is better for more accurate measurement results.

Second aim

To determine if there is a gender differentiation in the palatal rugae patterns in Saudi Arabian, Aseer Region population.

Null hypothesis

The shapes and measurements of 24 subjects were collected for this study and based on that a 12 of the sample are males and the other 12 are females, thus there is no differentiation between male and female according to the size of the sample. The null hypothesis was accepted and the related conclusion drawn from the study was: Based on the sample number of the palatal rugae for the 24 samples, it was not enough to show a big differentiation between both genders. Therefore, shapes and measurements are similar to each other. However, shapes and measurements in the first right palatal rugae showed a significant differentiation between both genders especially in the wavy shape for the male over the female.

Third aim

There is a biometrical characteristic that allows the palatal rugae to be a promising identification based biometrics tool in forensic odontology.

Null hypothesis

Palatal rugae criteria are not applied to the biometrics based identification techniques. The null hypothesis was rejected and the related conclusion drawn from the study was: The biometrics based identification criteria were;

Uniqueness: No two persons should be the same in term of the characteristics.

Universality: Every person should have the characteristics.

Permanence: Characteristic should be invariant with time.

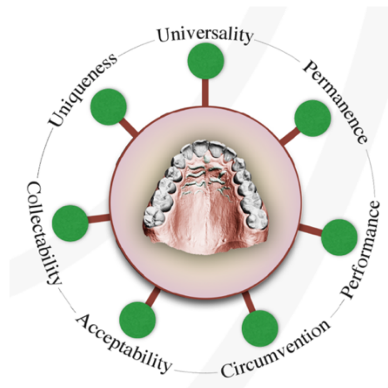
Collectability: Characteristic can be measured quantitatively.

Performance: The achievable identification accuracy.

Circumvention: How easy it is to fool the system by fraudulent technique.

Acceptability: To what extent people are willing to accept the biometric system.

Based on all previous literatures, palatal rugae are fulfilling the Uniqueness, Universality, Permanence, Collectability, Performance, and Circumvention. The only problem of the criteria was the acceptability. However, the workflow and the identification pattern generating through this study is easing the acceptability for further investigators to reject the idea that the palatal rugae is not acceptable biometrics based identification.



Fourth aim

There is a way to create and generate an biometrics based identification using the palatal rugae.

Null hypothesis

The extraction of shapes and measurements of the palatal rugae cannot be used as a biometrics based identification in the field of forensic odontology.

The null hypothesis was rejected and the related conclusion drawn from the study was: A new, comprehensive 3D method based on landmark configuration for the incisive papilla as well as the accurate measurements of the ArchLen()

method is applicable and useful in the generating a biometrics based identification for the field of forensic science in general and the field of forensic odontology in particular.

<u>Summary of Discussion:</u>

- To create a new classification scheme for the purpose of extracting the palatal rugae identification.
- Palatal rugae pattern have the same criteria that other biometrics based identification have; therefor, palatal rugae is considered as one of the multimodal biometrics tools in the field of forensic odontology.
- The advantage of using 3D image of the palatal rugae is to get the accurate measurement.
- The use of FRPR is to simplify the way of extracting the palatal rugae identification.
- The average number of rugae in females was slightly higher in comparison with that in males and the diverging pattern was found more commonly in females compared with males. Further studies need to be explored on varying population.
- The rugae morphological pattern may be useful in forensic science in case of mutilation when compared with other parts of the body.
- Palatal rugae form an intrinsic and integral pattern for every single individual and can also help in sex determination.

- The ease of reproducibility and lower level of variation makes palatal rugae a potential tool in forensic odontology.

5.5 Recommendations

The current study raises interesting questions about the potential for future studies using more sophisticated technique, such as the following:

- To establish a central database for storing the palatal rugae dataset to get back to it in the cases of identification search.
- To involve more subjects in the study for better gender and ethnicity differentiation and creating bigger dataset.
- To station an intra-oral scanner outside for the purpose of usage outside the laboratories for faster analysis for those who undefined.

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APPENDEX I:

In the following pages, 24 cases have been displaced with a descriptive data about each case measurement for the palatal rugae with respect of the following:

- number of rugae;
- the rugae side (R) for right side of the palate, and (L) for the left side of the palate;
- the distance in (mm) between the incisive papilla and the beginning of the rugae (Papilla_a);
- the distance in (mm) between the incisive papilla and the ending part of the rugae (Papilla_b);
- the radio in (mm) between Papilla_a and Papilla_b (Ratio);
- the distance in (mm) between the Median Raphe and the palatal rugae (Displacement);
- the thickness in (mm) of the rugae (Thickness);
- the shape of the rugae based on Lysell's classification (Shape); and the length of the rugae itself in (mm).

Table 41 All Measurements for Palatal Rugae Case : 1

CASE No. 1								
N	Side	Papilla_a (mm)	Papilla_b (mm)	Ratio (mm)	Displacement (mm)	Thickness (mm)	Shape	Length (mm)
1	R	12.1	5.3	2.28	1.5	2	curved	10.1
2	R	13	9.6	1.35	1.1	1.7	wavy	12.2
3	R	19.5	15.9	1.23	1.4	1.2	curved	15.1
4	R	22.4	19.8	1.13	10.9	0.9	straight	4.1
5	R	27.4	18.4	1.49	8.4	0.8	wavy	10.2
6	R	21.1	20.2	1.04	4.8	0.6	curved	5.1
7	L	12	5.5	2.18	2	1.7	curved	10
8	L	12.3	9.8	1.26	1.2	1.6	branched	11.2
9	L	14.9	12.8	1.16	8.1	1	straight	2.3
10	L	13.7	13.7	1.00	5.8	0.7	straight	1.5
11	L	16.1	16.3	0.99	2.5	1.8	wavy	11.1
12	L	18.8	17.3	1.09	11.4	0.7	straight	3
13	L	21.3	20.2	1.05	1.5	0.9	wavy	14.9

Table 42 All Measurements for Palatal Rugae Case : 2

CASE No. 2								
N	Side	Papilla_a (mm)	Papilla_b (mm)	Ratio (mm)	Displacement (mm)	Thickness (mm)	Shape	Length (mm)
1	R	8.6	10.2	0.84	5.5	2.2	straight	6.4
2	R	14.5	13.1	1.11	8.9	1.9	curved	6.2
3	R	18.9	7.1	2.66	2.4	1.4	wavy	24.9
4	R	27.6	12.3	2.24	0.5	1.3	wavy	28.3
5	L	11.8	10.9	1.08	0.7	1.5	curved	16.6
6	L	11.3	9.7	1.16	4.6	2.6	straight	7
7	L	14	15.2	0.92	2.1	1.7	wavy	12.6
8	L	16.2	16.6	0.98	14	1	straight	4.4
9	L	18.3	18.7	0.98	14.3	1.4	curved	6.6

10	L	22.7	16.9	1.34	5.2	1.2	wavy	15.3
11	L	19.9	20.7	0.96	3.9	1.1	straight	4.2

Table 43 All Measurements for Palatal Rugae Case : 3

CASE No. 3								
N	Side	Papilla_a (mm)	Papilla_b (mm)	Ratio (mm)	Displacement (mm)	Thickness (mm)	Shape	Length (mm)
1	R	8.1	6.4	1.27	0.8	1.7	straight	8.7
2	R	9.7	10.7	0.91	7	2.7	straight	6
3	R	13.9	12.8	1.09	8.9	1.3	curved	4.7
4	R	15.8	7.9	2.00	1	1.4	wavy	16.4
5	R	18.5	15	1.23	1.1	1.3	curved	16.1
6	L	8.3	5	1.66	1.2	1.5	curved	21.8
7	L	12.5	11.8	1.06	8.3	1.1	straight	5.2
8	L	17.6	15.2	1.16	2.1	1.8	wavy	13.5
9	L	23.5	16.5	1.42	4.4	0.6	wavy	11.7

Table 44 All Measurements for Palatal Rugae Case : 4

CASE No. 4								
N	Side	Papilla_a (mm)	Papilla_b (mm)	Ratio (mm)	Displacement (mm)	Thickness (mm)	Shape	Length (mm)
1	R	8.9	5.8	1.53	0.7	1	wavy	9
2	R	10.6	8.6	1.23	5.3	1.2	curved	4.1
3	R	15.4	12.4	1.24	1.3	1.1	wavy	15.7
4	R	18.8	18.2	1.03	8.9	0.8	wavy	7
5	R	21.6	15.6	1.38	1.5	1	straight	10.2
6	L	9.7	11.7	0.83	1.4	0.9	branched	12.2
7	L	11.3	9.1	1.24	3	1.2	curved	8.1
8	L	12.6	16.2	0.78	7	0.7	curved	9.1
9	L	13.3	14.7	0.90	2.4	1.1	curved	5.9
10	L	15.7	18	0.87	11.4	1.1	straight	5.2

11	L	19.7	20	0.99	3	0.7	straight	12.5

Table 45 All Measurements for Palatal Rugae Case : 5

CASE No. 5								
N	Side	Papilla_a (mm)	Papilla_b (mm)	Ratio (mm)	Displaceme nt (mm)	Thickness (mm)	Shape	Length (mm)
1	R	6.2	6.7	0.93	0.7	0.9	curved	5.6
2	R	10.7	9.4	1.14	1.9	0.9	wavy	8.3
3	R	13.3	14.5	0.92	1.5	1.9	curved	9.2
4	R	16.8	21.3	0.79	1	0.8	wavy	14.5
5	R	22.6	19.6	1.15	9.5	1.1	branched	10.8
6	L	14.1	14.7	0.96	0.8	1.5	wavy	23.5
7	L	14.2	14.2	1.00	4	1.3	curved	1.8
8	L	15.4	15.7	0.98	5.9	1	curved	9.2
9	L	17.2	19.2	0.90	1.9	0.8	curved	5.5
10	L	23	21.6	1.06	6.6	0.9	branched	11.5

Table 46 All Measurements for Palatal Rugae Case : 6

CASE No. 6								
N	Side	Papilla_a (mm)	Papilla_b (mm)	Ratio (mm)	Displaceme nt (mm)	Thicknes s (mm)	Shape	Length (mm)
1	R	14	7.2	1.94	1.3	2.2	branched	10.4
2	R	15.5	11.7	1.32	1	1.4	wavy	15
3	R	20.1	18.1	1.11	12	1	wavy	5.9
4	R	18.3	17	1.08	2	0.8	wavy	5.6
5	R	23.7	19	1.25	8.1	1	wavy	9.6
6	R	21.8	20.5	1.06	5.6	0.9	straight	3.1
7	L	9	8.6	1.05	0.9	2	curved	16.5
8	L	14.6	14.2	1.03	8.5	0.7	wavy	4.9
9	L	16.5	14.2	1.16	1.6	1	wavy	16.1
10	L	20.2	15.2	1.33	2.4	1.1	wavy	13.2

11	L	19.5	18.7	1.04	11.7	0.9	curved	5
12	L	20.7	23.1	0.90	12	0.6	straight	7.1

Table 47 All Measurements for Palatal Rugae Case : 7

CASE No. 7								
N	Side	Papilla_a (mm)	Papilla_b (mm)	Ratio (mm)	Displacement (mm)	Thickness (mm)	Shape	Length (mm)
1	R	11.8	9.2	1.28	0.9	2.3	curved	9.7
2	R	13	10.2	1.27	0.8	2	wavy	11
3	R	15.4	14.6	1.05	3	1.8	curved	14.4
4	R	21.3	15.6	1.37	1.8	0.5	wavy	20.7
5	R	21.4	21.6	0.99	0.8	0.5	straight	3.3
6	L	17.1	9.3	1.84	1	1.4	wavy	21.9
7	L	12.8	21.1	0.61	1	0.9	wavy	18.3
8	L	10.4	10.9	0.95	0.7	1	straight	1.6
9	L	17.7	22.2	0.80	7.1	0.4	straight	11.5

Table 48 All Measurements for Palatal Rugae Case : 8

CASE No. 8								
N	Side	Papilla_a (mm)	Papilla_b (mm)	Ratio (mm)	Displacement (mm)	Thickness (mm)	Shape	Length (mm)
1	R	9.2	7.4	1.24	7.2	1.4	curved	2.3
2	R	11.3	5.1	2.22	1	1.9	curved	10.7
3	R	13.2	9.4	1.40	5.7	1.2	wavy	5.7
4	R	17.6	13	1.35	7.7	1	straight	5.9
5	R	15.9	9.8	1.62	0.7	1.5	wavy	10.7
6	R	21.3	17.6	1.21	1	0.9	branched	11.5
7	R	21.5	21.4	1.00	8.5	1	curved	4.1
8	L	12.5	7.7	1.62	1	0.9	wavy	13
9	L	13.9	10.5	1.32	4.8	1.1	wavy	6.7
10	L	14.2	13.3	1.07	7.4	0.8	curved	2.6

11	L	16.6	16.1	1.03	9.7	1.2	curved	3.8
12	L	20	14.3	1.40	0.9	1.4	branche d	15.6
13	L	21.1	18.2	1.16	1.5	1	wavy	10.3

Table 49 All Measurements for Palatal Rugae Case : 9

CASE No. 9								
N	Side	Papilla_a (mm)	Papilla_b (mm)	Ratio (mm)	Displacement (mm)	Thickness (mm)	Shape	Length (mm)
1	R	8.9	7.2	1.24	0.6	1.8	Branched	10.7
2	R	15.3	12.9	1.19	0.9	1.2	Wavy	16.4
3	R	18.6	18.5	1.01	1.5	1.3	Wavy	14.1
4	L	10	7.7	1.30	1	1.9	Curved	12.1
5	L	9.8	13.8	0.71	2.2	1.6	Branched	11.7
6	L	12.6	11.2	1.13	9.6	0.7	Wavy	2.9
7	L	14.5	11.7	1.24	8	1.6	Curved	6

Table 50 All Measurements for Palatal Rugae Case : 10

CASE No. 10								
N	Side	Papilla_a (mm)	Papilla_b (mm)	Ratio (mm)	Displacement (mm)	Thickness (mm)	Shape	Length (mm)
1	R	4.5	6.4	0.70	0.6	1.2	Wavy	7.8
2	R	6.6	7.9	0.84	0.4	1.4	Wavy	12.5
3	R	11.1	10.3	1.08	1.1	1.6	Wavy	13
4	R	13.5	15.2	0.89	1.1	1.3	Wavy	16.5
5	R	17.1	16.7	1.02	13	0.8	Straight	6.3
6	R	17.5	17.2	1.02	8.8	0.8	Curved	4.5
7	R	20.2	19.4	1.04	7.7	0.4	Curved	7.8
8	R	19	19.2	0.99	1.8	1.1	Curved	4.3
9	L	8.2	8.1	1.01	1.4	1	Wavy	11
10	L	9.9	12.6	0.79	0.7	0.7	Branched	13.3

11	L	14.4	16.8	0.86	0.7	1.6	Wavy	17.1
12	L	16.6	17.1	0.97	12	0.5	Straight	5.5
13	L	19.7	19.8	0.99	2.6	1	Straight	3.6
14	L	19.3	20.6	0.94	8.2	0.5	Straight	5.3

Table 51 All Measurements for Palatal Rugae Case : 11

CASE No. 11								
N	Side	Papilla_a (mm)	Papilla_b (mm)	Ratio (mm)	Displaceme nt (mm)	Thickness (mm)	Shape	Length (mm)
1	R	4.7	2.8	1.68	1.5	0.4	Straight	3.5
2	R	12	8.5	1.41	0.5	1.3	Ring	17.4
3	R	14.1	12.7	1.11	0.6	1	Wavy	17.2
4	R	17.5	16.9	1.04	7.2	0.6	Wavy	11.5
5	R	19.8	20.1	0.99	13.1	1	Straight	4.4
6	R	21.1	16.5	1.28	1.5	0.6	Curved	8.3
7	L	9.5	7.2	1.32	1.1	1.7	Wavy	10.4
8	L	10.5	9.6	1.09	1.9	2	Branched	11.1
9	L	15.4	12.8	1.20	1.2	0.9	Wavy	15
10	L	17.3	19.8	0.87	1.6	0.9	Curved	4.3

Table 52 All Measurements for Palatal Rugae Case : 12

CASE No. 12								
N	Side	Papilla_a (mm)	Papilla_b (mm)	Ratio (mm)	Displacemen t (mm)	Thickness (mm)	Shape	Length (mm)
1	R	9.9	9.5	1.04	0.8	1.2	Branched	14.3
2	R	17.2	12.8	1.34	3.5	1.5	Wavy	14.1
3	R	13.3	17.9	0.74	0.7	1.2	Curved	6.1
4	R	19.4	16.9	1.15	4.7	1	Wavy	17.2
5	L	8.9	10.6	0.84	0.6	1.2	Branched	13.3
6	L	13.9	18.2	0.76	2.5	1.1	Wavy	16.2
7	L	17.1	17.4	0.98	7.1	1.1	Curved	11.4

8	L	20.5	20	1.03	3.2	0.4	Straight	4.5
9	L	25.5	23.2	1.10	12.7	0.6	Wavy	5.2
10	L	20.5	21	0.98	9.1	0.5	Wavy	11.8

Table 53 All Measurements for Palatal Rugae Case : 13

N	Side	Papilla_a (mm)	Papilla_b (mm)	Ratio (mm)	Displacement (mm)	Thickness (mm)	Shape	Length (mm)
1	R	12.3	7.3	1.68	1.2	1.3	Branched	11.9
2	R	17.8	13	1.37	2.8	1.1	Wavy	12.9
3	R	22.8	20.1	1.13	5	0.7	Wavy	11.7
4	R	16.5	23.4	0.71	1.2	0.8	Straight	7.9
5	L	9.9	8.4	1.18	2	1.3	Wavy	12.1
6	L	12.2	9.5	1.28	6.2	1.7	Curved	6.8
7	L	15.4	12.1	1.27	4.3	1.8	Wavy	12.9
8	L	19	14.6	1.30	2	0.8	Wavy	20
9	L	21.9	23.4	0.94	15.9	0.7	Straight	4.4
10	L	26.1	25	1.04	7.6	0.8	Curved	8

Table 54 All Measurements for Palatal Rugae Case : 14

CASE No. 14								
N	Side	Papilla_a (mm)	Papilla_b (mm)	Ratio (mm)	Displacement (mm)	Thickness (mm)	Shape	Length (mm)
1	R	9.1	3.1	2.94	1.3	1.7	Curved	12.3
2	R	8.9	6.8	1.31	0.8	1	Straight	5.3
3	R	12.7	10.9	1.17	6.5	1.9	Curved	6.6
4	R	17.9	8.7	2.06	2.2	1.3	Curved	16.3
5	R	20.5	18.1	1.13	10.8	0.9	Straight	8.4
6	R	21.4	16.7	1.28	0.7	0.8	Wavy	10.4
7	L	4.3	3.1	1.39	0.7	0.7	Straight	4.6
8	L	9.2	8.4	1.10	1	1.6	Ring	12.2

9	L	16.3	14.6	1.12	1.8	1.9	Wavy	16
10	L	17.8	17.9	0.99	10.3	1.4	Wavy	6.1
11	L	22.1	22.4	0.99	2.5	0.6	Wavy	18.1

Table 55 All Measurements for Palatal Rugae Case : 15

CASE No. 15								
N	Side	Papilla_a (mm)	Papilla_b (mm)	Ratio (mm)	Displaceme nt (mm)	Thickness (mm)	Shape	Length (mm)
1	R	10	7	1.43	0.7	2	Branched	12.5
2	R	9.8	9.1	1.08	6.8	0.9	Straight	4.4
3	R	10.6	10.5	1.01	9.3	0.5	Straight	1.8
4	R	13.3	7.8	1.71	4	1	Wavy	10.9
5	R	13.5	14.3	0.94	9.7	0.8	Straight	5.4
6	R	15.6	11.1	1.41	0.9	0.8	Wavy	16.8
7	R	17.6	20.6	0.85	11.3	0.8	Wavy	8.6
8	R	19.3	15.3	1.26	3	0.3	Straight	9.1
9	L	11.1	12.3	0.90	0.8	0.9	Ring	19.4
10	L	12	10.5	1.14	5.6	1.1	Wavy	10
11	L	13.1	12.8	1.02	5.2	1	Curved	10.2
12	L	16.9	17.3	0.98	7.8	0.6	Straight	11.7
13	L	16.1	16.3	0.99	1.2	0.6	Wavy	6.2

Table 56 All Measurements for Palatal Rugae Case : 16

CASE No. 16								
N	Side	Papilla_a (mm)	Papilla_b (mm)	Ratio (mm)	Displaceme nt (mm)	Thickness (mm)	Shape	Length (mm)
1	R	6.6	7.4	0.89	0.9	1.4	Curved	7.9
2	R	10.7	8.5	1.26	7.2	1.2	Wavy	3.4
3	R	12.2	10.6	1.15	8.9	0.9	Wavy	2.3
4	R	13.9	13.6	1.02	3	1.9	Wavy	12.5
5	R	15.1	14.9	1.01	10	1.1	Curved	2.2
6	R	20.6	16.1	1.28	6.6	0.8	Wavy	10.9

7	R	19.5	17.2	1.13	5.2	0.6	Wavy	6.4
8	R	22.4	21.7	1.03	9.8	0.7	Straight	6.9
9	L	9.5	9.1	1.04	0.8	1	Ring	10.9
10	L	11.8	11.8	1.00	8.4	0.8	Straight	2.3
11	L	12.5	12.2	1.02	4.6	1	Straight	1.3
12	L	13.6	14.2	0.96	5.6	1.3	Wavy	7.5
13	L	16	17.4	0.92	5.4	0.9	Curved	3
14	L	16.4	20.8	0.79	6.5	0.7	Wavy	12.7
15	L	18.4	24	0.77	8.6	0.6	Wavy	12.3
16	L	24.2	24.9	0.97	11.6	0.5	Straight	3.6

Table 57 All Measurements for Palatal Rugae Case : 17

CASE No. 17								
N	Side	Papilla_a (mm)	Papilla_b (mm)	Ratio (mm)	Displaceme nt (mm)	Thickness (mm)	Shape	Length (mm)
1	R	7.6	5	1.52	4.6	0.7	Straight	2.7
2	R	16.6	7.1	2.34	0.7	2.1	Branched	16.9
3	R	21.3	17.9	1.19	13.5	0.4	Wavy	4.2
4	R	16.5	12.8	1.29	3	0.7	Wavy	7.3
5	L	5.8	2.9	2.00	2.9	6	Straight	3.1
6	L	8.4	7.8	1.08	3.5	1.8	Curved	8.4
7	L	7.8	6.3	1.24	1.6	0.8	Straight	1.7
8	L	10.8	9.6	1.13	6	1.4	Curved	6
9	L	15.9	10.9	1.46	3.5	1	Wavy	13
10	L	10.6	12.4	0.85	2	0.9	Straight	1.9
11	L	15.1	14.9	1.01	5	0.8	Curved	8.1

Table 58 All Measurements for Palatal Rugae Case : 18

CASE No. 18								
N	Side	Papilla_a (mm)	Papilla_b (mm)	Ratio (mm)	Displaceme nt (mm)	Thickness (mm)	Shape	Length (mm)
1	R	11	8.1	1.36	1.5	1.7	Branched	10

2	R	12.1	12.8	0.95	8.2	0.8	Straight	2.7
3	R	15.2	12.4	1.23	0.7	1.5	Wavy	11.4
4	R	19.2	14.1	1.36	2.2	0.7	Curved	11.6
5	R	18.6	17.7	1.05	0.6	0.4	Curved	2.4
6	L	11.9	10.5	1.13	1.3	1.2	Branched	15.8
7	L	13.5	13.5	1.00	0.9	1	Wavy	9.1
8	L	15.1	18.9	0.80	1.4	0.6	Branched	17.6
9	L	17.2	19.1	0.90	11.8	0.7	Curved	6.1
10	L	20.8	22.9	0.91	9.7	0.3	Curved	4.7

Table 59 All Measurements for Palatal Rugae Case : 19

CASE No. 19								
N	Side	Papilla_a (mm)	Papilla_b (mm)	Ratio (mm)	Displaceme nt (mm)	Thickness (mm)	Shape	Length (mm)
1	R	10.5	9.4	1.12	1.6	2.6	Curved	12.5
2	R	12	10.1	1.19	6.7	1.8	Straight	5.8
3	R	15.1	14.6	1.03	0.7	2.2	Wavy	16.4
4	R	20.3	15.7	1.29	11.4	0.8	Wavy	6.1
5	R	18.9	16.5	1.15	1.7	1.3	Wavy	12.5
6	L	11.5	9.5	1.21	0.7	2.6	Ring	14.5
7	L	13.6	12.7	1.07	8.9	1.9	Straight	6.1
8	L	12.8	15.6	0.82	1.7	2.1	Wavy	9.8
9	L	14.9	18.2	0.82	4.7	1.1	Straight	13.6
10	L	18.6	20.5	0.91	2.2	0.7	Straight	2.6
11	L	18.4	20	0.92	9.1	0.8	Straight	9

Table 60 All Measurements for Palatal Rugae Case : 20

CASE No. 20								
N	Side	Papilla_a (mm)	Papilla_b (mm)	Ratio (mm)	Displacemen t (mm)	Thickness (mm)	Shape	Length (mm)
1	R	11	9.7	1.13	0.5	1.5	Branched	1.9

2	R	13.3	11.2	1.19	4.8	1.5	Wavy	8.9
3	R	15.1	14	1.08	10.9	0.5	Wavy	3
4	R	16.1	18.5	0.87	0.8	1.4	Branched	16.5
5	R	19.2	19.4	0.99	2.4	0.5	Wavy	11
6	R	21.8	18.3	1.19	10.7	0.5	Branched	4.9
7	L	12.1	13.1	0.92	0.6	1.9	Branched	18.5
8	L	14.2	14.2	1.00	10.8	0.4	Curved	3.2
9	L	13.3	16.2	0.82	1	1	Straight	5.2
10	L	17.4	18.7	0.93	2.1	1.3	Wavy	19.1
11	L	23.4	21	1.11	12.8	0.8	Curved	5.4

Table 61 All Measurements for Palatal Rugae Case : 21

CASE No. 21								
N	Side	Papilla_a (mm)	Papilla_b (mm)	Ratio (mm)	Displacement (mm)	Thickness (mm)	Shape	Length (mm)
1	R	9.9	5.5	1.80	1.1	0.7	Curved	9.4
2	R	11.6	6.8	1.71	0.3	0.6	Branched	13
3	R	18.3	13.9	1.32	7.5	0.8	Wavy	10.2
4	R	20.1	12.2	1.65	1.4	0.7	Branched	19.2
5	R	22.2	20.7	1.07	8.1	0.6	Straight	2.4
6	R	25.5	25.6	1.00	10.7	0.6	Curved	6
7	L	7	5.4	1.30	3.6	0.3	Curved	4.7
8	L	10.4	9.5	1.09	1.2	0.5	Ring	17.1
9	L	14.4	14.5	0.99	1.2	1	Curved	13.1
10	L	17.8	19.6	0.91	5	0.9	Wavy	14.2
11	L	19.5	22.1	0.88	10.3	0.6	Curved	9.8

Table 62 All Measurements for Palatal Rugae Case : 22

CASE No. 22								
N	Side	Papilla_a (mm)	Papilla_b (mm)	Ratio (mm)	Displacement (mm)	Thickness (mm)	Shape	Length (mm)

1	R	9	4.5	2.00	1.3	1.5	Curved	17.6
2	R	16.7	8	2.09	0.5	1.2	Wavy	18.7
3	R	18.8	15.4	1.22	11	0.6	Wavy	9.7
4	R	14.5	12	1.21	1.1	0.9	Wavy	15.3
5	R	21.3	22.1	0.96	9.9	1	Wavy	17
6	L	11.5	9.9	1.16	1.2	1.5	Curved	11.5
7	L	12.5	9.6	1.30	6.2	1	Straight	7.1
8	L	14.5	11.6	1.25	3.3	0.9	Wavy	11.5
9	L	18	15.2	1.18	10.5	0.4	Curved	6.9
10	L	19.1	13.3	1.44	1.8	1.1	Wavy	16.7
11	L	20.2	22.4	0.90	14.6	0.5	Straight	5.3

Table 63 All Measurements for Palatal Rugae Case : 23

CASE No. 23								
N	Side	Papilla_a (mm)	Papilla_b (mm)	Ratio (mm)	Displaceme nt (mm)	Thickness (mm)	Shape	Length (mm)
1	R	9.3	5.2	1.79	5.5	1	Branched	11.3
2	R	12.5	11.4	1.10	7.3	1.2	Curved	4.6
3	R	16.5	11.1	1.49	5.2	0.7	Wavy	10.6
4	R	20.8	14.6	1.42	2	0.9	Wavy	15.4
5	L	11.3	8.5	1.33	1.3	1.1	Wavy	12
6	L	12.1	12.1	1.00	8.5	0.7	Wavy	2.9
7	L	10.7	11.9	0.90	5.5	1.4	Curved	5.9
8	L	9.3	10.5	0.89	1.5	0.6	Straight	1.2
9	L	12.3	11.7	1.05	0.9	0.9	Curved	1.5
10	L	13.7	14.9	0.92	3.7	1.4	Wavy	12.4
11	L	16.3	17.4	0.94	9.3	0.6	Straight	4.9
12	L	19.5	17.9	1.09	8.2	0.8	Straight	1.6
13	L	19.8	19.1	1.04	4.2	0.5	Curved	3.8

14	L	22.3	21.2	1.05	8.2	0.6	Wavy	8.3

Table 64 All Measurements for Palatal Rugae Case : 24

CASE No. 24								
N	Side	Papilla_a (mm)	Papilla_b (mm)	Ratio (mm)	Displacement (mm)	Thickness (mm)	Shape	Length (mm)
1	R	5.8	5.8	1.00	1.4	1.2	Straight	5.2
2	R	10.8	9.6	1.13	1.2	2.2	Branched	11.5
3	R	13.7	11.9	1.15	9.1	0.9	Straight	2
4	R	16.7	13.4	1.25	1	1.1	Wavy	14.8
5	R	20.2	18.9	1.07	6.9	0.6	Straight	5.4
6	R	25.6	23.3	1.10	8	0.5	Wavy	11.3
7	R	22.3	17.2	1.30	3.1	1.3	Straight	11.3
8	R	23.4	23.3	1.00	2.7	0.4	Straight	3.8
9	L	4.1	5.1	0.80	0.9	0.6	Straight	3.3
10	L	11.4	9.4	1.21	1.1	1.1	Curved	21.1
11	L	12.8	12.7	1.01	0.8	0.9	Straight	5
12	L	16.4	14.6	1.12	1.3	1.1	Wavy	14.8
13	L	19.3	18.5	1.04	8.3	0.8	Wavy	11.4
14	L	21.8	22.8	0.96	16.1	1.3	Straight	2.5
15	L	25.2	18.8	1.34	0.9	0.7	Wavy	19.3