RUGOSCOPY: AN INNOVATIVE APPROACH TO FORENSIC IDENTIFICATION

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Abstract

This review article highlights the importance of rugoscopy in forensic investigations. Palatal rugae, also known as the "rugae palatina" are the irregular ridges of tissues located on the anterior part of palatal. Due to their unique and individualized nature, palatal rugae have become an essential tool for forensic investigator in the identification of human remains. The paper provides an overview of the anatomy and formation of palatal rugae, including their classification and variations among individuals. The article further explores the current techniques and technologies used in palatal rugae analysis, including traditional methods such as the photographic and cost analysis, as well as modern methods like computer assisted techniques, including the use of digital images and 3D scanning. Additionally, the article examines the advantages and limitations of using palatal rugae for forensic identification, including its noninvasive nature, low cost and resistant to decomposition. Finally, the review concludes with the importance of continued research into palatal rugae analysis to further advance forensic identification techniques and increase accuracy in forensic investigations. As a future perspective of the study despite of having several limitations, the potential application of robocopy in forensic science are significant and advances in the same field are also likely to play a significant role in future. For example, the use of artificial intelligence and machine learning could potentially improve the accuracy and speed of palatal rugae analysis various cases of mass disasters, mass graves forma where there are no other evidences like DNA and fingerprint available. One challenge in this field is the potential individual variation in the formation and appearance of palatal rugae. Additionally, the use of rugoscopy as a standalone method of identification may not always be feasible or generally accepted and other method used to be utilized in conjunction with it. As technology continues to advance the use of rugosa scope in forensic science is likely to become even more widespread and valuable.

Keywords: Rugoscopy, Forensic investigations, Forensic identifications, Palatal rugae, Future aspects.

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INTRODUCTION

Forensic odontology has been defined as a specialized branch of dentistry that involves the application of dental knowledge to legal matters. It primarily involves the use of teeth and dental records in the identification of human remains and determination of cause of death or injury in cases where identity of victim is known[1]. Forensic odontology is evolving as a golden method for identification of unknown person in mass destruction, fire or burned body and even decomposition. For these types of cases where fingerprints are not available palatal rugoscopy is used[2].

The exact function of palatal rugae is not fully understood but it is believed that they aid in speech and swallowing of food by providing friction and increasing the surface area which helps in holding food during mastication. It also contributes in perception of taste texture[3], [4].

Palatal rugae also known as palatal ridges or rugae palatine, are series of asymmetrical ridges located on anterior portion of hard palate, that is bony structure that forms the roof of the mouth[3], [5].

They are formed in the 3rd month of intrauterine life and they do not change their shape except its length which increases with the increase of age[3]. Anatomically 3 to7 ridges are present in rugae and few ridges radiate out tangentially from incisive papilla[6]. Due to the hydrophilic nature of the abundant glycosaminoglycans the shape of palatal rugae is maintained. Specific pattern of rugae is determined by the connective tissues composed of fibroblast and collagen[7], [8].

The formation of palatal rugae is a complicated process which involves various steps like mesenchymal cell proliferation, palatal shelf outgrowth, elevation, fusion, and eventually disappearance of midline epithelial line[9]. The genetic pathway of rugae development involves signaling pathway and transcription factors. Classic activation-inhibitor system is required which is an interaction between fibroblast growth factor and Sonic hedgehog signaling pathway[10]. Sonic hedgehog (SHH) signaling pathway is the key player as SHH is a secreted protein that plays an important role in embryonic development including craniofacial pattern and palatal formation. SHH is expressed in mesenchyme of developing palate. This expression is regulated by several transcription factors including MSX1, PAX9, WNT10A and AXIN2. These transcription factors control the formation of teeth and other structure of mouth and is also important for patterning and morphological development of tooth and taste buds. Any mutation in these genes or transcription factor leads to oligodontia and tooth agenesis which means group having one or more permanent teeth (excluding 3rd molar) that are not present at birth[10]. There is a potential genetic link between rugae and tooth development which is expressed in developing dentition and is established in association with the variations of interferon regulatory factor 6 (IRF6) in families with sporadic hypodontia[10], [11].

Other signaling pathway is involved apart from SHH signaling pathway which helps in the development of palatal rugae. Bone morphogenetic protein (BMP) is an important participant in craniofacial and palatal rugae development. BMP regulates mesenchymal proliferation along with SMAD (suppressor of mother against decapentaplegic) which is found in rugae development[9].

Another important signaling pathway is WNT pathway. WNT protein is involved with left-right asymmetry in palatal rugae. The mutation in WNT signaling genes have been linked to craniofacial abnormalities like cleft palate or lips along with many other defects of tooth and palate[9]–[11].

Palatal rugae examination is in non-invasive reliable and cost-effective tool for establishing an individual's identity. It is essential to follow a standardized methodology to ensure accurate and reproducible results. Palatal rugae examination can also be combined with other biometric tools such as fingerprints and DNA analysis to enhance identification accuracy.

OBJECTIVE OF THE STUDY

In this paper, we study about the process of taking dental casts for analysis purpose. We discuss about the variations that occur in palatal rugae for identification purpose among population, gender, siblings and twins as well as among patients with orthodontic treatment. It helps us in determining the uniqueness of the palatal rugae and its forensic significance.

PROCEDURE FOR THE EXAMINATION OF PALATAL RUGAE

Patient selection: palatal rugae examination can be performed on individuals of any age group and gender. However, it is essential to exclude individuals who have undergone any surgical

procedures in the oral cavity that could have altered the palatal rugae[12]–[14].

Collection of data: a detailed patient history, including age, gender, ethnicity and medical history, should be collected. A thorough clinical examination of the oral cavity should also be performed to assess the palatal rugae's characteristic[15]–[18].

Palatal impression: a dental alginate impression material is used to obtain an accurate impression of the maxillary arch. The patient is instructed to rinse their mouth with water, and the impression material is placed on the palate. The impression is then allowed to set, and material is removed from the oral cavity[17], [19], [20]. Sometime the impressions are taken digitally using Emerald intraoral scanner with ROMEXIS PlanCAD Easy software[21] and SLR digital camera (Canon EOS 300D)[6].

Cast preparation: the impression is poured with dental stone to obtain a cast of the maxillary arch. The cast is allowed to set and is then trimmed to remove any excess material[20], [22].

Rugae identification: the palatal rugae morphology is analyzed and recorded on the cast using a magnifying glass or a microscope. The rugae's length, shape, direction and position are recorded to establish a rugae pattern[15], [23], [24].

Rugae classification: palatal rugae can be classified based on their shape direction and position. The most commonly used classification is the Thomas and Kotze classification which categorized palatal rugae into 6 types straight, curved, wavy, circular, converging and diverging. It also includes the rugae length as primary (5mm or more), secondary (3mm to 5mm) and fragmentary (2mm to 3mm) which was taken from Lysell classification and incorporated into Thomas and Kotze classification[7], [15], [16], [25].

Analysis of Rugae pattern: the rugae pattern is analyzed and compared with existing databases to stablish the individual's identity. Various software programs such as Palatal Rugae Comparison Software (PRCS version 2.0) has been developed to aid in rugae pattern analysis[6]. Image recognition technology was also introduced and a 3D palatal rugae recognition method was also proposed which was based on isometric slicing and cyclic spectral analysis which is used for complete digitalization of the palatal rugae[26]. Sometime upper and lower jaw are analyzed by the obtaining 3D digital model using iTero HD 2.9 intraoral digital scanner[27].

Accuracy assessment: the accuracy of palatal rugae examination has been reported to range from 70% to 100% depending on the study design, sample size, and examiner's expertise.

POPULATION VARIATION

The characteristics of rugae changes from one single population to another. Harchandani N et al., demonstrated in the research that western Indian subjects have straight and wavy shape whereas northern Indian subject showed wavy and curved rugae shape. When comparing these two-population divergent unification was more in males while females had converging unification [25]. Saleem et al., discovered that both males and females in Rajasthan's Mewar and Hadoti regions have wavy pattern followed by curve, straight and diverging patterns on both side of rugae. They also discovered that males had greater total number of rugae than females, on the other hand, both males and females have a similar number of rugae on the left side of the palate[15]. Shwetha K Shetty et al., discovered differences in Mysorean and Tibetian populations where on the left side of palate, Mysorean males had more primary rugae than Tibetian males and Tibetian females had more rugae than their counterpart. Mysorean had more curve shape and Tibetian had more wavy shaped rugae. Males in both the population have diverging rugae[23]. Sundanese had wavy and curved as most common rugae and Malaysian Tamils have curved followed by wavy[28]. In Igbos and Yoruba, two different ethnicities have differences in secondary and unclassified rugae[29]. Rath and Reginald identified a new non-specific rugae pattern in considerable amount in Andhra Pradesh population which was termed as 'plaque pattern'. These unique feature helps in identification of an individual and rugae study can help in better utilisation in population differences and ethnic differentiation[24].

GENDER VARIATION

Many researchers have worked on numerous factors that provide different results denoting that palatal rugae are indeed unique in nature within a single population where males and females gave different results to prove that palatal rugae may serve as an identification factor in forensic investigation. Studies have shown that males have higher number of primary rugae, having straight

and wavy shape with divergent unification[7], [30]–[32]. The study of palatal rugae among siblings it is observed that males have longer rugae length than females due to larger dimensions of head and former also had more primary rugae and lesser secondary rugae comparing to the latter because of the wide palate. The total number is also higher in males than in females[20]. The same set of studies have shown that female have secondary and fragmentary rugae in higher ratio with curve and wavy pattern along with convergent unification[14], [30]–[34] Some studies gave opposite and contrasting results like male having curved and sinus pattern, converging unification and female having straight or curved or wavy or circular pattern with divergent unification. The left side of the palate, females have primary rugae whereas males have secondary rugae. The width and the height of palatal rugae are more in males than in females with former having asymmetrical rugae alignment whereas latter having horizontal alignment [12], [14], [22], [33], [35].

TWINS

Sir Galton proposed that twin research be carried out to help define the role of hereditary and environmental influences in determining the form and size of the human body. Mirror imagining has been noticed both in monozygotic as well as dizygotic twins based on the shape and number of primary rugae[17]. Significant differences in the shape of the right rugae were noticed in dizygotic twins, inferring that shape can be used to distinguish these individuals[36]. The number of rugae on the left side of the palate is indeed a significant difference among dizygotic twins. In accordance with the study, there are resemblances between siblings in the first right rugae, which has a straight shape[20]. With similarities between twins, significant hereditary components were observed.

PRE- AND POST- TREATMENT

Palatal rugae not only remain constant throughout life, but they are also said to be immune to orthodontic treatment. Some studies yield contradictory results. In several studies related to edentulous cases, it is said that the stability of rugae is in medial points and not lateral points[8], [37]. It is said that the closer they are to the teeth, the more they stretch in the direction of tooth movement [13], [38]. Rugae points are unstable in the transverse direction in relation to primary rugae lateral points[38]. Posterior rugae are less vulnerable to the changes during tooth movements [37]. The inter rugae distance which consist of medial and lateral distance between 1st and 4th rugae pair on both side of the raphe shows significant differences when pre- and post-treatment models are compared[16]. The length of the third rugae is thought to have increased following the treatment of rapid palatal expander [39] but several studies also showed that 2nd and 3rd rugae or secondary rugae is the stable rugae and can be used as an identification factor[2], [13], [37].

DISCUSSION

Males have more divergent, straight rugae, while females have converging, circular, or wavy rugae, according to studies[32]. Rugae shape is comparable between father and son rather than mother and son, but there are minute differences that demonstrate that they are unique to each individual[30]. Researchers have demonstrated that orthodontic treatments have no effect on the palatal rugae[10], [16], [37], [40]. Only when antemortem and postmortem models are accessible can palatal rugae be examined for identification [16], [38]. Hereditary components that were similar between sibling pairs were visible, and it also talks about both genetic and environmental influences on rugae[20], [41].

Palatal rugae have really no impact on survivors of fire incidents or burn victims with pan facial burns of the third degree. This illustrates that rugae could withstand decomposition for up to 7 days postmortem when preserved in proper conditions. It is also speculated that the cause of death may have an effect on the decomposition process[30], [42]. Secondary or 3rd palatal rugae are considered better identification evidence than primary rugae. Some studies have discovered no significant variations between pre and post extraction and orthodontic treatment, confirming the stability of rugae over time[1], [2], [16], [37], [40]. Studies have additionally demonstrated that palatal geometrics (width, height, and depth) can be used as collaborative pieces of evidence for sex determination, with palatal width providing a higher level of accuracy and palatal shape for differentiating the populations[43], [44].

CONCLUSION

The study of palatal rugae has received a great deal of interest in forensic odontology because of their uniqueness, individualistic, and stability. The results of palatal rugae analysis can provide vital information to identify an individual and aid in the process of personal identification in a variety of fields such as forensic sciences, anthropology, and

dentistry. This review paper examines the rugae pattern in both males and females in great detail. This literature also suggests that the number, shape, and orientation of palatal rugae patterns varies significantly between populations. According to the majority of studies, females have more rugae than males. This review emphasis the limitations of the study of palatal rugae, such as the lack of standardization in rugae pattern analysis methodology and the possibility of intra and inter examiner variability in identification. Rugae pattern analysis using imaging techniques is a promising approach for individual identification. More standardization and methodological improvements, however, are required for more accurate and reliable results. Overall, the study of palatal rugae patterns is an intriguing field of study which has the potential to provide critical information in personal identification and should be pursued further.

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