Elevating Forensic Odontology: 3D Printing for Customized Palatal Rugae Oral Mannequin

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ABSTRACT
Background:

Forensic odontology plays a critical role in individual identification for mass casualty incidents or mutilation victims. Through dental records and oral structures, including palatal rugae. Palatal rugae, being stable and unique, are valuable for forensic identification. However, traditional oral mannequins used for rugoscopy education lack the diversity of palate patterns required for comprehensive training. To address this challenge, we propose leveraging 3D printing technology to create customized oral mannequins.
Method:

Using a prototype design approach, oral mannequins were designed with distinct palatal rugae patterns using 3D design software. The resulting designs were 3D printed using resin and polylactic acid filament materials. Subsequently, we employed an Anycubic M3 4K+ resin 3D printer to manufacture these customized mouth mannequins. To evaluate the prototype's functionality and limitations, we conducted a SWOT analysis.
Result:

Resin emerged as the preferred material, offering high resolution and intricate detailing. Our research successfully demonstrated the production of an oral mannequin, each featuring unique palatal rugae patterns, using a resin-based 3D printer. The utilization of resin as the printing material ensured the creation of intricately detailed and smooth palatal rugae structures.
Conclusion:

This research presents a significant advancement in forensic education by leveraging 3D printing to create tailor-made oral mannequins, featuring unique palatal rugae patterns. This innovation holds the potential to enhance rugoscopy education, contributing to the field of forensic odontology and its critical applications in victim identification and criminal investigations.

Keywords: *3D printing, forensic education, forensic odontology, identification, oral mannequins, palatal rugae, rugoscopy*

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1. INTRODUCTION

Forensic odontology, a pivotal branch of forensic science, focuses on individual identification through dental records and oral structures, including palatal rugae [1]. Palatal rugae, also known as palatal ridges or rugae palatinae, constitute intricate, asymmetrical, and distinct ridge patterns situated on the hard palate behind the anterior teeth. These patterns manifest during prenatal development and remain remarkably stable throughout a person's lifetime [2]. Palatal rugae, typically located on either side of the median palatal raphe behind the incisive papilla, offer a unique advantage in identification due to their permanence and resilience to external influences [3]. Shielded within the oral cavity, palatal rugae endure minimal exposure to external trauma, preserving their integrity. This stability and uniqueness render them invaluable in forensic science, particularly when traditional identification methods such as dental records prove unavailable [4]. The examination of palatal rugae for identity confirmation, and aligning antemortem and postmortem data, is known as rugoscopy [5].

To date, forensic odontology has relied on human and conventional oral mannequins. However, these models fall short of providing the diverse palate patterns necessary for comprehensive rugoscopy education. Simultaneously, significant advancements have occurred in 3D printing technology for medical applications [6]. 3D printing involves the layer-by-layer construction of three-dimensional objects and offers advantages such as customization, precision, and material versatility. Multiple technologies cater to various medical printing needs, depending on the application and material [7]. Therefore, this study proposes harnessing 3D printing technology to craft tailor-made oral mannequins, addressing the limitations of traditional methods.

2. METHOD

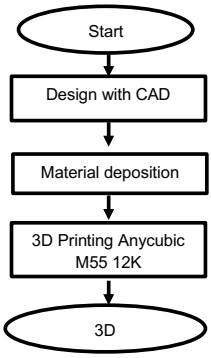

Figure 1 Flowchart of the 3D Printing Technology

This research adopts a prototype design methodology, as illustrated in Figure 1. The goal is to create oral mannequins boasting diverse palatal rugae patterns. The oral mannequin design process involved Shapr3D, a 3D design software.

We produced two mannequins using polylactic acid filament and resin materials, respectively. The resin material was initially treated with our New Anycubic Photon Wash and Cure 2.0. The resin 3D printer utilized was the Anycubic Photon M3 4K+, as depicted in Figure 2. The polylactic acid filament 3D printer utilized was Crealty Ender V2 Pro.

Figure 2 Resin 3D Printer Used

We also conducted a SWOT analysis of this prototype. The composition of this research article was aided by Grammarly and ChatGPT, an artificial intelligence tool developed by OpenAI. ChatGPT contributed to refining the report's language, while Grammarly was employed for grammar and syntax verification.

3. RESULT

Figure 3 illustrates the 3d design outcomes, prepared for 3d printing. Resin and polylactic acid filament were used as materials. Both materials employed the same design; however, resin material proved superior due to its high resolution, rapid printing speed, smooth surface finish, and capacity for intricate detailing. It offers a clearer representation of the patient's palate. Conversely, the attempt to 3d print an oral mannequin using polylactic acid filament material resulted in failure. Figure 4 showcases the resin 3d-printed oral mannequin.

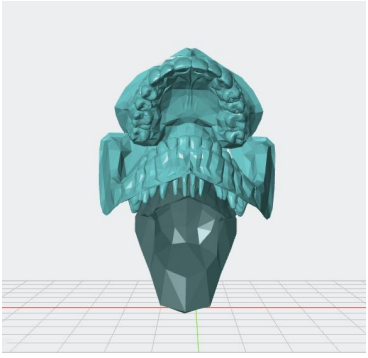

Figure 3 Oral mannequin design with palatal rugae

Figure 4 Resin 3D Printed Oral Mannequin

Figure 5 Failed PLA Filament 3D Printed Oral Mannequin

To evaluate the prototype's functionality and limitations, we conducted a swot analysis.

Strengths:

Our approach enhances access to customized oral mannequins while maintaining production efficiency, particularly relevant to medical and dentistry institutions and forensic odontology.

Weaknesses:

The palatal rugae were not as clearly defined in our prototype.

Opportunities:

The demand for affordable and customized oral mannequins presents an opportunity to enhance hands-on training for future healthcare professionals, including dentists, medical practitioners, forensic specialists, and forensic odontologists.

Threats:

Operational challenges, technical errors, and varying 3d printer results are potential constraints associated with the mannequin printing processes. Addressing these issues is critical for the seamless integration of 3d printing technology in the medical field.

4. DISCUSSION

In light of the literature review, it is evident that the morphological characteristics of palatal rugae exhibit significant interindividual variability. The conceptual framework for developing a three-dimensional (3D) mannequin draws inspiration from photographic records captured prior to orthodontic interventions by dental professionals. A notable illustration of leveraging patient photographs as foundational references for mannequin construction is exemplified in the seminal case report authored by Taneva et al. [8]. This pioneering study elucidated the process of palatal rugae identification in identical twins, wherein an oral photograph of these siblings served as the basis for subsequent stereolithographic endeavors.

Stereolithography, a widely employed rapid prototyping technique, holds prominence for generating tangible models, intricate patterns, and functional components via a sequential additive manufacturing process from computer-aided design (CAD) software through the medium of three-dimensional (3D) printing. Notably, intraoral digital scanning, particularly utilizing the iTero system, harnesses stereolithography apparatus technology to engender digital replicas of oral mannequins [9]. In this context, patients underwent intraoral scanning procedures facilitated by the iTero system, with resultant digital models exported in the binary stereolithography format (*.stl) via the MyAlignTech platform. The *.stl format, being a ubiquitous industry standard, finds extensive application in the realm of additive manufacturing and diverse 3D modeling interfaces [10]. Subsequent phases encompassed the meticulous evaluation, judicious selection, and precise extraction of the palatal rugae region. Furthermore, a sophisticated 3D matching and superimposition protocol was executed to meticulously overlay the palatal rugae patterns using the imported *.stl files, employing the venerable professional engineering processing software, Geomagic Control 14, developed by Geomagic, located in Research Triangle Park, NC, USA. The paramount criterion for palatal rugae documentation pertained to their dimensional length and structural attributes [8].

These pioneering investigations have yielded notable outcomes attributed to the incorporation of dedicated digital scanning devices designed specifically for oral imaging purposes. This technological advancement has substantially elevated the fidelity of palatal rugae visualization, rendering it markedly superior and more precise compared to the outcomes achieved through our conventional 3D design approach. Consequently, the integration of a specialized 3D scanner emerges as a prospective avenue for augmenting the precision and specificity of 3D-printed oral mannequins, opening vistas for enhanced accuracy and fidelity in palatal rugae replication and representation.

5. CONCLUSION

In conclusion, our exploration of 3D printing technology in the realm of rugoscopy underscores the preference for resin material in creating reliable oral mannequins. The application of 3D printing represents a substantial advancement in forensic education, facilitating the development of customizable oral mannequins with diverse palatal rugae patterns. This innovation holds the potential to significantly enhance rugoscopy education, furthering the field of forensic odontology and its vital applications in victim identification and criminal investigations.

AUTHORS' CONTRIBUTIONS

The authors confirm contribution to the paper as follows: study conception and design: 1. Thareq Barasabha, 2. Astika Swastirani, and 3. Eriko Prawestiningtyas. Data collection: 1. Aminatus Zakiyah, 2. Muhammad Abdul Raziq; Analysis and interpretation of results: 1. Thareq Barasabha, 2. Muhammad Abdul Raziq; draft manuscript preparation: 1. Thareq Barasabha, 2. Aminatus Zakiyah, 3. Muhammad Abdul Raziq. All authors reviewed the results and approved the final version of the manuscript.

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