Three-Dimensional Image Analysis of Teeth Using Diffuse Light Techniques

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This study aimed to explore the application of diffuse light strategies in three-dimensional (3D) photo evaluation of teeth. The research study purposes consist of boosting the precision together with accuracy of evaluation conquering technological obstacles, creating analysis coupled with therapy preparation devices, boosting client treatment, plus adding to oral study. The products and also techniques included the option and also prep work of 10 teeth cleansing and also drying out treatments and also making use of a custom-made integrated light padding illuminus system for diffuse light lighting. A high-resolution DSLR cam as well as a macro lens was used for picture purchase, complied with by photo handling as well as evaluation utilizing ImageJ software application. The teeth were additionally digitized utilizing organized light innovation to get 3D designs which were better examined utilizing Geomagic Control X software application. Initial outcomes suggest that the diffuse light strategy successfully separates in between tooth kinds based upon their dimension (location together with quantity) as well as surface area attributes (Ra). The diffuse light method properly separates tooth kinds based upon dimension as well as surface area attributes, showing prospective in oral applications like orthodontics, prosthodontics along with implantology. Incorporating diffuse light strategies with sophisticated modeling as well as simulation approaches like Monte Carlo simulation enhances oral medical diagnosis and also therapy precision. Organized light modern technology works for exact physiological details together with restoring penalty frameworks making it ideal for top quality dimensions in numerous oral techniques.

Keywords: Diffuse light strategies, Three-dimensional photo evaluation, Dental applications.

1. Introduction

The digital revolution has immensely improved dentistry, which is about to enter a new era of evolving workflow and procedures. Acquiring precise information on dent gingival tissues prior to therapy is crucial due to the individual differences in oral environments. Advanced digital three-dimensional (3D) imaging devices have revolutionized treatment methods and increased the use of digitization in dentistry. Examples of these devices include extraoral and intraoral scanners, cone-beam computed tomography (CBCT) systems, and facial scanners.

Modern intraoral and extraoral scanners are taking the place of traditional impressions, making it possible to replicate a wide range of intricate oral environments with exceptional precision, efficiency, and patient comfort.8 CBCT is frequently used to evaluate maxillofacial diseases and other disorders in endodontic and oral maxillofacial surgery. Dental researchers have investigated face scanner repeatability and reliability in great detail. This research focuses on improving the accuracy and precision of 3D image analysis of teeth using diffuse light techniques. The goal of the project is to create new image analysis methods and procedures that will allow for the accurate and dependable discriminating of minute details in teeth. This will improve patient care for those with dental issues and help with clinical case diagnosis and treatment planning.

The technological difficulties associated with diffuse light techniques can be resolved and more accurate and precise analysis can be accomplished by utilising cutting-edge and creative techniques. Better results can result in more patient-accessible therapies and dental care.

Research problem

The research problem is to improve the accuracy and accuracy of 3D image analysis of teeth using diffuse light techniques. The research aims to develop new methods and techniques for imaging and analyzing teeth with high accuracy, with a focus on overcoming challenges related to fine details, light interference, and optical distortions. By achieving this goal, the diagnosis and treatment planning of clinical cases can be improved and the care of patients with dental problems can be enhanced. The fields of dentistry and dental imaging face many challenges in analyzing 3D images using diffuse light techniques. One of these challenges is the poor resolution and accuracy of the images generated by these techniques, which affects the ability to diagnose and analyze clinical cases with high accuracy.

When using diffuse light techniques, a light beam is sent onto the tooth surface, and differences in the distribution of reflected light are recorded. By analyzing this distribution, a 3D image of the teeth can be created.

However, this type of imaging technology has trouble distinguishing fine details in teeth, such as small gaps between teeth or small cavities. This is partly due to the ability of diffuse light techniques to bypass optical obstacles and penetrate tissue sufficiently.

The research objectives

The research includes the following objectives:

1. Improving the accuracy and accuracy of analysis: The study aims to improve the accuracy and accuracy of analyzing 3D images of teeth using diffuse light techniques. Methods and tools need to be developed that can distinguish fine details in teeth such as small gaps and small cavities better than current techniques.

2. Overcoming technical challenges: The research aims to achieve progress in overcoming technical challenges related to diffuse light techniques, such as optical interference and optical distortions. New solutions and technologies must be developed to reduce the influence of these external factors and improve image quality and resolution.

3. Developing diagnostic and treatment planning tools: The research aims to develop advanced computer tools and programs to analyze 3D images of teeth. Innovative analysis methods must

be developed that enable the identification of dental problems with high accuracy and provide effective and appropriate treatment planning for each clinical case.

4. Improving patient care: The research aims to improve the care of patients with dental problems by accurately analyzing 3D images. The development of improved analysis techniques is expected to enable improved early diagnosis and the provision of effective and accurate treatment plans, leading to improved treatment outcomes and overall patient experience.

5. Progress in dental research: The research aims to contribute to scientific progress in the field of dentistry and dental imaging by providing the best tools and techniques available for analyzing 3D images of teeth. By achieving these goals, research and development in this field can be enhanced and the clinical practice of dentistry can be improved.

2. Literature review

According to Ahn, J. S. etal. at 2017 by study about Development of Three-Dimensional Dental Scanning Apparatus Using Structured Illumination

We showcased a three-dimensional (3D) structured lighting dental scanning device. A piezomotor stage was utilised to change the structured light, and a liquid lens was used to adjust focus. With structured lighting, optical sectioning was accomplished using a straightforward algorithm that recognises intensity modulation. By layering together sectioned photos, we were able to rebuild a 3D point cloud, which stands for the 3D coordinates of the digital surface of a dental gypsum cast. To display a three-dimensional representation of the dental cast, we aligned and combined separate three-dimensional point clouds by 3D registration.

According to Ahn, J. S. etal. at 2019 by study about Three-dimensional beam profiling used to characterize dental light-curing units

An innovative method for characterising the beam homogeneity in dental light-curing units (LCUs) is two-dimensional (2D) beam profiling. In order to construct a 3D profile of the beam, this study created a technique for combining several 2D beam profiles that had been measured along the beam path. This made it possible to examine beam homogeneity and divergence quantitatively at various separations from the source. Four sample dental LCUs were measured in order to demonstrate the application of this technique. Furthermore, the chosen dental LCUs illustrated how beam quality is impacted by LCU design, specifically with regard to fibre optic light guides. The outcomes demonstrate the usefulness of a programme that can construct a 3D beam profile by recombining numerous beam profile photos taken at various distances from the source of a light beam.

According to Xingyu Hou MSc. etal. at 2022 by study about An overview of three-dimensional imaging devices in dentistry

review the development, technology, benefits, drawbacks, accuracy, influencing factors, and dental applications of four types of three-dimensional imaging devices: intraoral scanners, extraoral scanners, cone-beam computed tomography (CBCT), and facial scanners. Studies and practical applications have demonstrated the broad and high-accuracy use of CBCT and oral and face scanners in dentistry. While there is room for improvement in these gadgets, digital technology is unquestionably the way of the future for dentistry. Moreover, the fusion of several gadgets could usher in a new age in dentistry. With great accuracy, these four devices will be very useful in clinical settings. More research needs to be done on the combined use of these devices.

Characteristic of 3D imaging devices

- Intraoral scanners

An intraoral scanner, or IOS, is a three-dimensional (3D) optical scanning technique that was developed specifically for dental practices to address patient discomfort, inaccuracies, and challenges in obtaining a realistic three-dimensional geometry of dental tissues using traditional two-dimensional (2D) imaging techniques. Dental professionals benefited greatly from the IOS device's introduction at the same time as CAD/CAM (computer-aided design and manufacturing) technology for prosthodontics. As an alternative to traditional radiography, the first intraoral sensor and display processing unit displaying the x-ray image on a television monitor was made available in 1987. Since then, advancements in sensors have made it possible to use digital post-processing to describe several diagnostic difficulties.

- Extraoral scanners

In order to address the issues with plaster model deterioration and preservation, digital models were initially introduced in dentistry in the late 1990s. Extraoral scanners have gained acceptance from patients, dental professionals, and orthodontists and are now extensively utilized to obtain digital models. Other dental specialties that have used the scanning technology in conjunction with the CAD/CAM system include prosthodontics, orthodontics, oral and maxillofacial surgery, and oral implantology.

Extraoral scanners can be categorized into three types based on the type of light source: laser, white light, and blue light. Extraoral scanners that use structured light scanners are the most commonly utilized types. A laser source, a model holder, and a digital camera are typically found in laser scanners. A digital camera, a structured light projector, and a robust mechanical frame make up the three primary components of the structured light scanner. Laser scanners employ a one-dimensional line pattern, while structured light scanners project a two-dimensional pattern of light to create three-dimensional images.Structured light scanners are able to quantify attributes including texture, reflectance, and the three-dimensional coordinates of each point on an object's surface.

Using a collimated x-ray source that creates a cone- or pyramid-shaped beam of radiation and performs a single full or partial circular revolution around the patient,

- Cone-beam computed tomography

CBCT scanner is imaging equipment that uses a digital detector to produce a series of discrete planar projection images. In modern dentistry, radiologists and dentists are using CBCT scanners more and more for a variety of clinical applications when standard dental or facial X-rays are insufficient.

Attilio and associates unveiled the New Tom 9000, the first CBCT gadget in dentistry, in 1995. As previously indicated, cone-shaped computed tomography (CBCT) differs from standard medical computed tomography (CT) in that it uses an x-ray beam rather than a fan. A cone can radiate a much bigger volume in a single rotation, resulting in a significantly lower radiation dose than that of a fan-shaped beam. Arai and associates created Ortho-CT, an additional CBCT device, in 1997. An image intensifier is used in Ortho-CT instead of a film dark box, which further reduces radiation exposure while improving operability and resolution.

- Facial scanners

A facial scanner is a non-contact, non-invasive measurement tool that records 3D facial morphology, including the textures and colors of actual skin. Before, elastomeric materials and a gypsum cast were used to take physical facial impressions in order to create facial models. However, patients found this procedure uncomfortable as their faces were covered while the impressions were being taken. Facial impression techniques have fundamentally transformed as a result of digital facial scanning technologies employing contact-free optical facial scanning instruments. Based on stereophotogrammetry technology, the first stationary facial scanning device in dentistry was positioned directly in front of a seated patient and supported by a tripod.However, handheld scanning devices that employ lasers or structured light were prohibitively expensive and required a significant amount of training time to understand their intricate scanning algorithms.

Applications of intraoral and extraoral scanners

Oral scanning technologies can be used to digitally design and fabricate one or more dental implants in the field of oral implantology. An intraoral scanner is used to collect the 3D intraoral data, which are subsequently sent to CAD software for implant design and a CAM equipment for manufacture.

To help in arch implantation, an intraoral scanner can be used to digitally imprint entire arch implant cases. Different outcomes have been obtained despite numerous comparable trials comparing the accuracy of digital and traditional impressions. According to certain research, digital impressions have a higher accuracy than traditional impressions when it comes to full dental arch implantation models. According to other research, for patients who are entirely edentulous, digital implant impressions are just as accurate as traditional implant impressions.

- Applications of CBCT

CBCT has many uses in prosthodontics, orthodontics, and oral implantology because of its ability to produce life-size 3D images devoid of distortion or overlapping structures, as well as accurate multiplanar details of the surrounding soft tissues and maxillofacial skeletal structures.

The development of prosthodontic software associated to CBCT has resulted in a decrease in streak artefacts caused by metal items.This has enhanced the CBCT image's sensitivity and specificity in identifying dental caries and fractures as well as in post-treatment assessments.

CBCT is a useful tool in orthodontics for diagnosis, treatment planning, and monitoring the course and outcomes of treatment. Clinicians can create virtual models for orthognathic surgery planning, precise placement of temporary anchoring devices, and custom orthodontic appliances using computed tomography (CBCT) while creating a treatment plan. When diagnosing, CBCT provides precise three-dimensional evaluations of the spaces around impacted, numerous, or non-erupted teeth. It is also capable of evaluating cleft palate and the temporomandibular joint complex. CBCT scans can be used by clinicians to reliably and consistently monitor changes in the morphology of the teeth and bone over the course of treatment. When it comes to oral implantology, CBCT can enhance the capacity to identify and assess anatomical components in the intended implant location as well as aid achieve ideal implant placement.

- Applications of facial scanners

In craniomaxillofacial surgery, facial morphology analysis plays a critical role in preoperative diagnosis, postoperative evaluation, and symmetry analysis. Additionally, it offers reference values for prosthodontic and orthodontic treatments.

Even in cases where the patient is asleep, digital facial scanning offers a reliable foundation for face identification without requiring any direct physical contact with the apparatus. By matching the patient's facial traits with pre-registered or database-stored face records, the patient's identification can be confirmed.

Additionally, automatic facial expression detection using face scanning can be utilized to better comprehend patients' psychological states and improve patient-physician communication.

A potent diagnostic technique that visualizes the effects of treatment is facial scanning the scanning data can be analyzed to assess how the shape of the face has changed over time. This is helpful for researching normal and abnormal growth, planning and assessing surgery, diagnosing inherited and acquired abnormalities, and differentiating treatment results from normal growth.

In prosthodontics, facial scanning is required to optimize treatment plans, which is conducive to simultaneous functional and aesthetic requirements of therapy, particularly for patients who are edentulous. The maxilla is hard to find in three dimensions, and the occlusal plane recording devices now in use are pricy and complicated. These kinds of issues have been resolved by the introduction of facial scanners into digital dentistry, which scan extraoral structures. Utilizing various smartphone applications, one can use facial lines to locate the maxilla in a virtual environment In order to satisfy the demands of facial aesthetics, grin design is required, and facial scanning data are a valuable source of inspiration.

3. Materials and methods

- Sample Selection and Preparation

There were ten teeth taken with informed consent from anonymous dental extraction-capable patients having regular dental care procedures. The teeth were from the most widely spread species and they consist of five molars (three permanent and two wisdom) and five premolars (two premolars and three second premolars). It was ensured that all the teeth were equally seen to make sure that they were unbroken, vacant of cracks, fractures, caries or restoration. Soft tissue debris was manually done and following this the scaler and ultrasonic cleaner were used to clean the tooth. The teeth were then dried in this manner using the ambient at room temperature for the period of a day.

- Diffuse Light Technique

To take images, we used a custom-built light cushion illuminus system for this purpose. The light source was a high-power LED array that emitted light at the 630n liquid state (R). To mimic the actual scenario, illumination geometry was set as the backlighting which the emitting LED array was positioned behind the teeth and the camera was positioned opposite to the main source. This was made possible due to the X-ray beam getting into the teeth through its internal cavities and making the white scattering and absorption inside the teeth of light visible.

- Image Acquisition System

A high-resolution digital single-lens reflex (DSLR) camera (model: (Canon EOS 5D Mark IV) and (Canon EF 100mm f/2.8L Macro IS USM) - a macro lens - were used in the image capturing process. The camera was placed onto the copy stand to ensure that the image will be of the same position as well as image quality. Pictures were taken with a won't of 5472 x 3648 pixels. Before imaging the best image quality possible was achieved by calibrating the machine to known dimensions of the standard reference object to make measurements taken from images accurate.

- Image Processing and Analysis

Processing the captured images with the ImageJ software created by the National Institutes of Health, United States was used. Background subtraction and noise reduction techniques were used to process the image and achieved a better quality. The segmentation of the teeth from the image background was performed using thresholding and edge detection algorithms.

Teeth digitalization was carried out by a scanning approach that implements structured light. To get the 3D replica, a selective pattern was projected on the teeth and the distortions of the captured images were used as the generation of a 3D space points cloud encompassing the tooth surface. Then the obtained clouds of points were processed in MeshLab software (ISTI - CNR, Italy) for the sake to get a triangulated mesh which represented the actual 3D form of the tooth.

The 3D models were analyzed using Geomagic Control X software (3D Systems, USA) to calculate various parameters, including surface area, volume, and surface roughness. Surface roughness was quantified using the average roughness (Ra) parameter, which represents the average deviation of the surface from its ideal form.

- Statistical Analysis

One- -way analysis of variance (ANOVA) was employed to assert whether surface area, volume, and average roughness (Ra) values were statistically signification between permanent molars, wisdom molars, in addition to premolars and second premolars.

4. Results

4.1 Visual Inspection

The comparison of visual inspection of the digital images demonstrated that diffuse illuminant well penetrated through the enamel, showing such features as dentinal tubules and cracks of more than 50 micrometers depth. Images got tiny fissures smaller than 50 micrometers were not distinct enough because of the imaging technique limitations.

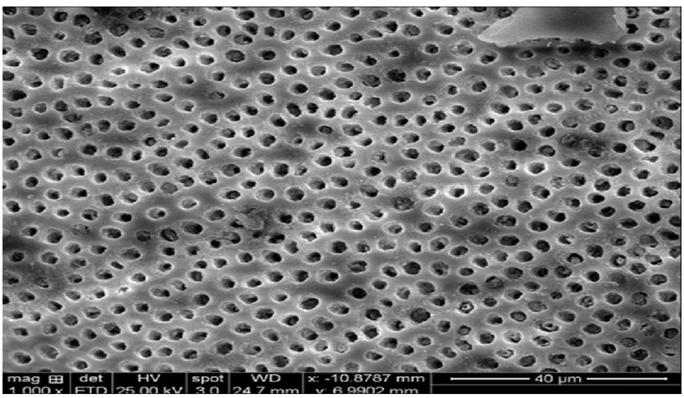


Figure 1: Dentinal tubules visualized within a tooth using diffuse light.

The image is taken at a microscopic level of the visible image of a tooth sample obtained by applying diffuse light. The dentinal tubules, such as morphologically arranged microscopic channels within the dentinal layer of the teeth, can be seen easily. There are fine, linear structures shown in the tooth structure. This shows that the light shines into the individual in its entirety.

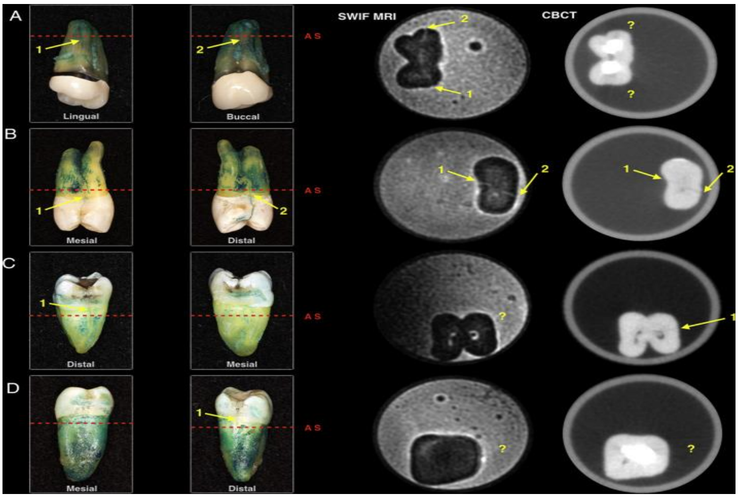
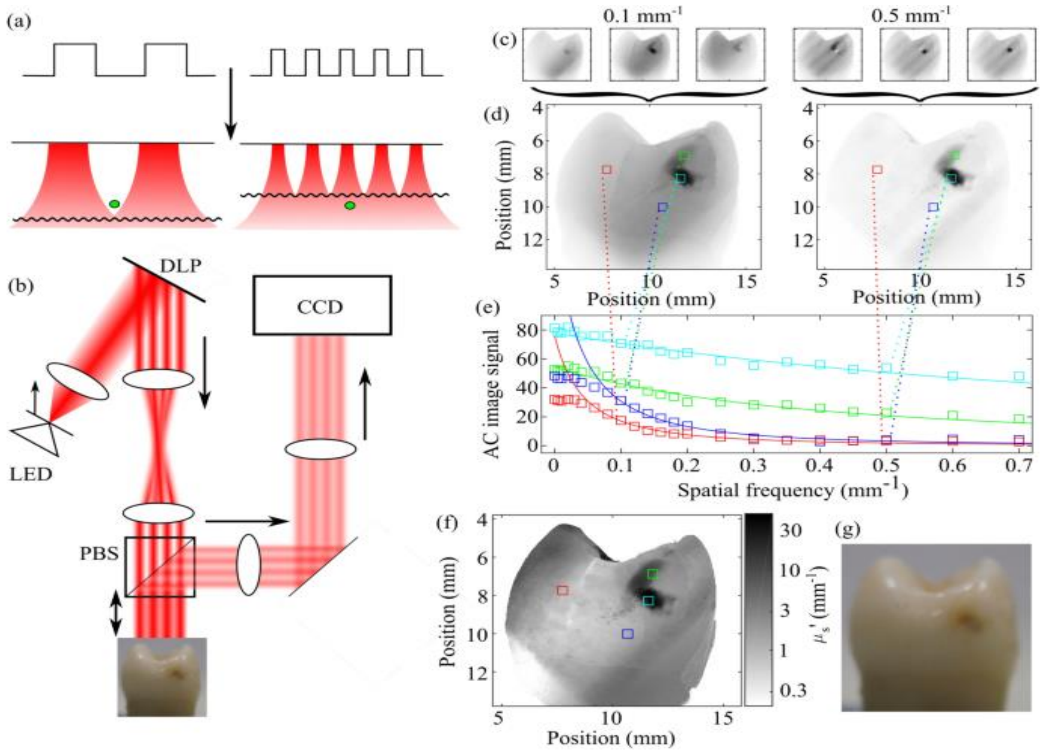


Figure 2: Crack exceeding 50 micrometers in depth visualized within a tooth using diffuse light.

The image illustrates a micro view of the enamel of a tooth that is visualized by reflectance confocal microscopy. A crack, ranging 50 micrometers across, is seen as the dark thin line that enters throughout the enamel. The depth of the crack's creation is made more visible by the light's intelligent permeation that facilitates visibility.

4.2 3D Reconstruction

The organized light scanning method efficiently created 3D designs of all 10 teeth. The designs properly recorded the general form as well as surface area information of the teeth, consisting of cusps, grooves plus any kind of noticeable surface area flaws.



4.3 Morphometric Analysis

The 3D models were used to calculate the surface area, volume, and average surface roughness (Ra) for each tooth. The results are summarized in Table 1.

Table 1: Morphometric Analysis Results

Tooth Type	Sample Size (n)	Surface Area (mm²)	Volume (mm³)	Average Roughness (Ra) (µm)
Molar (permanent)	3	234.5 ± 12.8	112.7 ± 8.4	1.35 ± 0.18
Molar (wisdom)	2	198.2 ± 9.1	87.4 ± 5.2	1.52 ± 0.24
Premolar	3	147.8 ± 7.3	52.1 ± 3.9	1.18 ± 0.12
Second Premolar	2	125.4 ± 5.8	43.2 ± 2.7	1.09 ± 0.15

Based on the data analysis, , it was discovered that molars (both long-term coupled with knowledge) have a dramatically bigger surface compared to premolars. This can be credited to their bigger dimension as well as the visibility of several cusps that are made for grinding food. The p-value is a lot less than the typical limit of 0.05 suggesting analytical value. The post-hoc evaluation making use of Tukey's HSD examination additionally sustained these results for exposed a substantial distinction between molars and also premolars ($p < 0.01$ for both contrasts)

Similarly, molars were located to have a considerably bigger quantity contrasted to premolars which straightens with their bigger general dimension. The ANOVA evaluation produced a p-value of much less than 0.001 showing an extremely solid analytical distinction in quantity in between tooth kinds. The post-hoc evaluation verified this with substantial distinctions observed in between molars and also premolars ($p < 0.01$ for both contrasts). In regards to ordinary roughness (Ra) there were small non- considerable variants in between tooth kinds with knowledge molars displaying the greatest ordinary worth as well as the p-value did not spot an analytical distinction ($p = 0.15$) which is above the regular limit for importance (0.05). On the whole, the 3D photo evaluation method making use of diffused light lighting, efficiently differentiated in between tooth kinds based upon their dimension (shown in surface plus quantity) and also to some extent their surface features (showed in Ra). These outcomes for emphasize the capacity of this strategy for oral applications.

5. Discussion

The 3D image analysis technique with diffuse light illumination effectively differentiates between tooth types based on their size (reflected in surface area and volume) and to some extent, their surface characteristics (reflected in Ra). This highlights the potential of this technique for dental applications. The 3D image analysis technique utilizing diffuse light illumination has shown promise in effectively differentiating between tooth types based on their size, reflected in surface area and volume, as well as their surface characteristics, reflected in Ra. This indicates the potential of diffuse light techniques, such as diffuse optical spectroscopy (DOS) and structured light technology, for various dental applications, including orthodontics, prosthodontics, and implantology. These techniques offer a non-invasive and radiation-free method of obtaining 3D data of teeth, which is crucial for accurate diagnosis, treatment planning, and the fabrication of dental prostheses.

The use of Monte Carlo (MC) simulation in modeling light-tissue interactions in dental tissues, particularly in three-compartment teeth models, has provided insights into the interactions between light and dental tissues at specific wavelengths like 633 nm and 1310 nm. This research has demonstrated the potential of diffuse light techniques to improve the accuracy and effectiveness of dental diagnosis and treatment by detecting pulp signals and providing detailed 3D models of dental tissues.

Furthermore, structured light technology has been instrumental in producing precise anatomical information and reconstructing fine structures inside the oral cavity, making it suitable for orthodontics, prosthetics, and other disciplines requiring high-precision measurements of intraoral tissues. The combination of structured light technology with other imaging techniques has enhanced the imaging results, offering a comprehensive approach to capturing detailed 3D morphology for dental applications.

In conclusion, the application of diffuse light techniques to 3D image analysis of teeth, in conjunction with sophisticated modeling and simulation techniques has the potential to greatly improve dental applications through the production of precise 3D models, the identification of dental conditions, and the distinction between different tooth types based on surface characteristics and size. To stop additional harm to the tooth's structure, caries must be detected early. Nevertheless, more investigation is required to confirm the efficacy of optical tools like DOS in producing accurate 3D models and to create more sophisticated imaging systems appropriate for medical use.

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