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Echoes of Pocket-Exploring Periodontal Peaks with Photoacoustic Imaging (PAI)

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Abstract

Periodontal disease remains a significant public health concern, necessitating accurate and efficient diagnostic tools for timely intervention. Assessment of periodontal status with gold standard periodontal probe becomes unsophisticated because of its poor reproducibility and inter examiner bias. To overcome this limitation, PhotoAcoustic Imaging entered into the field as a boon. It utilises ultrasound frequency, optical fibre bundles integrated with transducer and cuttle fish ink as the contrast medium. It is highly reproducible with standard deviation of about 10%. Recently "HOCKEY-STICK STYLE TRANSDUCER" has been invented to image even the inaccessible posterior most regions. 'Implants-the smile sculptors' can also be assessed with PAI in case of peri-implantitis where the manual probing is not appreciable. This article will enlighten its principle, highlighting its potential for assessing pocket depth, soft tissue and bone status, review on its current challenges and future directions.

Keywords: Photoacoustic Imaging; Ultrasound; Periodontal Pocket; Cuttlefish Ink; Hockey Stick Style Transducer

Abbreviations

PAI: Photo Acoustic Imaging.

Introduction

Photoacoustic imaging (PAI) is the non-invasive, bioimaging modality to assess the status of the periodontal pocket, gingival status and the bone defects in a precised manner. It is one of the précised digitalised diagnostic technique which revolutionizes diagnostic precision in the field of Periodontology. It is a precised technology that utilises ultrasound and photoacoustic overlay imaging [1,2]. Photoacoustic imaging is a specialized imaging technique that combines the principles of optical and acoustic (ultrasound) technologies to visualize tissues. It is a diagnostic technique that uses pulsed laser light to illuminate tissues. The light is absorbed by various tissue components, causing them to rapidly expand and generate ultrasonic waves (sound waves). These ultrasonic waves are then detected and converted into detailed images that represent the internal structures of the tissues [3,4].

History

The photoacoustic effect was first observed in 1880 by Alexander Graham Bell, the scientist credited with inventing the first practical telephone. The development of lasers capable of generating short, but powerful, bursts of light at different wavelengths was key to making photoacoustic

imaging a viable imaging tool, said Reuben Mezrich.

As he explained in an editorial in the April issue of Radiology, these bursts of light create soundwaves in the area of the body where the light is absorbed. And by matching the optical wavelength to materials within the body, or those introduced into the body, such as contrast agents, it becomes possible to image various light absorbers.

Here's a breakdown of the term:

- **Photo**: This prefix relates to light or optical phenomena.
- **Acoustic:** This refers to sound waves or ultrasound.
- **Imaging:** This denotes the process of creating visual representations of objects or structures.

Discussion

Principle of PAI

Photoacoustic imaging is a hybrid imaging modality that combines the high spatial resolution of optical imaging with the deep tissue penetration of ultrasound. It works on the principle of photoacoustic, where tissues are exposed to short pulses of laser light. The light is absorbed by chromophores (such as hemoglobin or melanin) in the tissues, leading to a rapid thermal expansion and the generation of ultrasound waves. These ultrasound waves are then detected by transducers and used to construct detailed images of the tissue [5] Figure 1.

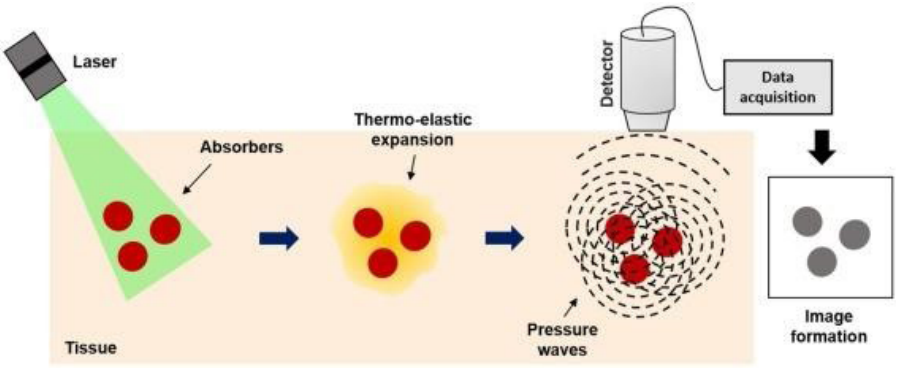


Figure 1: Principle of Photoacoustic Imaging.

Application of PAI in Periodontology

In periodontology, the primary focus is on the prevention, diagnosis, and treatment of periodontal diseases, which affect the supporting structures of the teeth, including the gums and bone. Photoacoustic imaging offers several advantages for periodontal assessments [6,7].

- **Enhanced Tissue Contrast:** Traditional imaging techniques like X-rays or standard ultrasound might not provide sufficient contrast between different soft tissue structures. Photoacoustic imaging can highlight the differences in tissue composition by exploiting the optical absorption properties of various chromophores, leading to better visualization of periodontal tissues.
- **Early Detection:** Periodontal diseases can start with subtle changes in the tissue that might not be visible through conventional imaging. Photoacoustic imaging can potentially detect these early changes by visualizing the vascular and inflammatory changes in the periodontal tissues.
- **Non-Invasive and Real-Time:** The technique is non-invasive and can provide real-time imaging, allowing for dynamic assessment of periodontal conditions. This can be particularly useful for monitoring disease progression and treatment efficacy.
- **Improved Diagnosis:** By providing detailed images of both soft and hard tissues, photoacoustic imaging can aid in a more accurate diagnosis of periodontal conditions. This can enhance the precision of treatment planning and help in personalized patient care.
- **Monitoring of Treatment Response**: During and after periodontal treatment, monitoring changes in the tissue structure and vascularization can be crucial. Photoacoustic imaging can be used to assess treatment outcomes more effectively compared to traditional methods.

Material and Methodology

Reagents and Equipments

Cuttle Fish Ink – it is a black coloured melanin containing food grade contrast agent commonly used in Mediterranean food items. It is also known as 'SEPIA'. PAI involves this dye as the contrast agent for digital pocket depth measurement. In general, this cuttle fish ink is a dark stained gel like substance ejected from a group of fish species example: cuttle fish as predator defence mechanism. It is composed of ink, water, salt, sodium carboxy methyl cellulose. Cornstarch is also used in preparation of the cuttlefish ink. It has anti-inflammatory, antibiotic and haematopoietic properties [8,9].

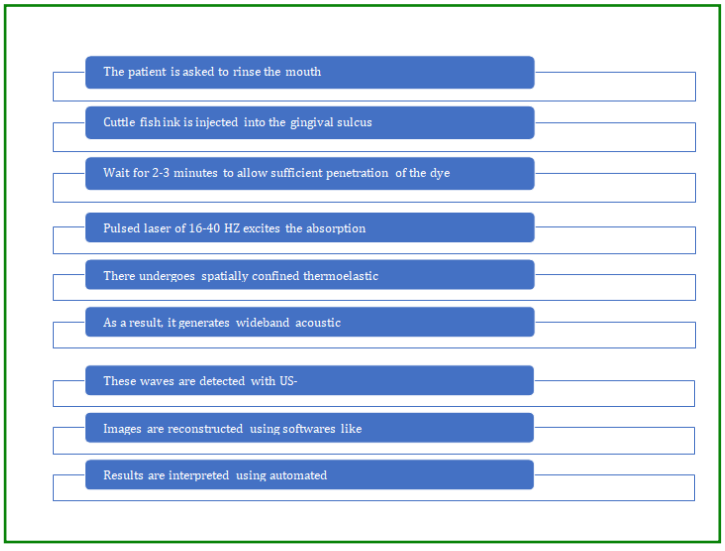
Melanin Nanoparticles in the dye acts as the contrast agent [10] Ultrasound Transducer [11,12] Software like verasonics

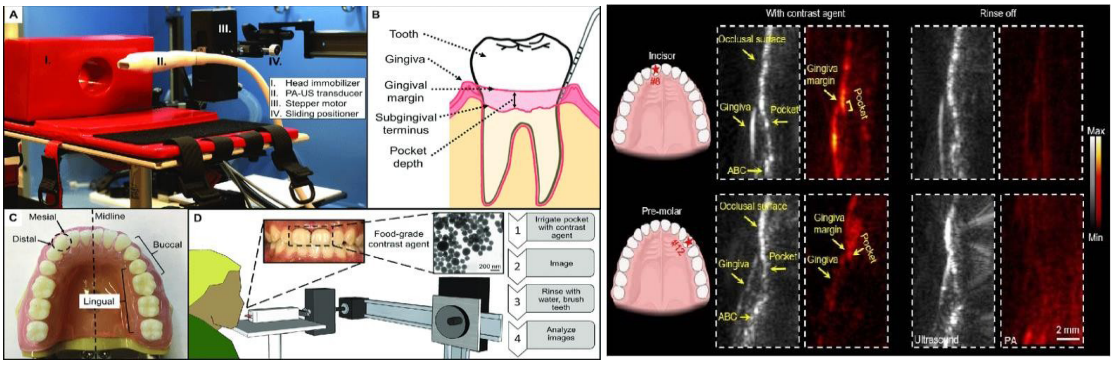
Based on a research article, a ultrasound transducer with a central frequency of 19 MHz and average – 6 dB bandwidth of 48.9 % was used. The transducer has 128 elements with element pitch of 78 μm. The laser diode generates laser pulses in 1 kHz in 808 nm. The pulse energy is 0.7 mJ/cm2 after coupling and the pulse width is 100 ns. A research ultrasound data acquisition system (Vantage; Verasonics, Inc., Kirkland, WA, USA) was used to receive, process, and reconstruct the photoacoustic/ultrasound signals Figures 2A & B & Figures 3A & 3B.

Figure 2A: Cuttlefish.

Figure 2B: Cuttlefish Ink.

Methodology





Figures 3A&3B: Mechanism of Pocket Measurement Using PAI.

Why do we Need Photoacoustic Imaging?

This technique plays its significant role in overcoming limitations of gold standard probing technique like [13].
Unreliable probe angulation
Improper probe insertion
Unreliable probing force

Ultrasound Transducer Design

The initial design of the US- transducer was little bit larger in size, thus its usage was limited only to the anterior region. Considering that, a newer design of the transducer with a modification in its shank is being designed to access even the inaccessible narrower posterior region of molars too. This design is termed as "Hockey Stick Style Transducer" [14,15]. To make the investigation and diagnosis even more easier and quicker, a tray is under designing process which would probably explore and interpret the periodontal pocket depth of all the teeth in the entire arch (maxilla/mandible) at a single snap Figures 4 & 5.

Figure 4: Hockey Stick Style Transducer.

Figure 5: Tray for Arch.

Advantages

Photoacoustic imaging in pocket measurement has enormous advantages over manual and conventional standard probing technique. It includes Windra Sari A & Hariri A, et al. [16,17]
Image both hard and soft tissues
More precise and real time imaging
Quicker investigation
Overcomes inter-examiner bias
Reduces patient discomfort
High resolution and contrast
Non-invasive procedure
Early detection
Enhanced personalised treatment
Enhanced research capabilities

- **Insights into Disease Mechanisms**: The technology provides researchers with new tools to study the mechanisms of periodontal diseases and evaluate novel therapeutic approaches.
- **Development of New Protocols:** Researchers can develop and refine imaging protocols that could lead

to improved diagnostic and treatment strategies in periodontology.

Disadvantages

Though a newer invention in diagnostic purpose has numerous pros, it also has its own disadvantages which should be keenly considered includes Windra Sari A & Hariri A, et al. [16,17].

Cannot be used in KOSCHER DIET patients- those who avoid sea foods in their diet

Technique sensitive

Complexity and cost

Limited clinical experience

Emerging Technology: Photoacoustic imaging is still relatively new in the field of periodontology. There is limited clinical experience and evidence regarding its long-term effectiveness, reliability, and overall impact on patient outcomes.

- Lack of standard protocols
- Data interpretation challenges
- Complex data analysis
- Need for expertise
- Tissue penetration limitations- Limited Penetration in Certain Tissues such as densely calcified structures or deep periodontal pockets.
- Potential image artifacts can be due to factors like tissue heterogeneity or movement.
- Patient adaptation

Clinical Highlight

This digitalised technique of periodontal assessment using photoacoustic imaging is highly significant in case of assessment of dental implants especially in scenarios of PERI-IMPLANTITIS, where conventional probing is not appreciable [18] Figure 6.

Figure 6: Peri-Implantitis.

Challenges and Future Directions

Despite its potential, photoacoustic imaging in periodontology is still in the research and development phase. Challenges include Khan S & Attia ABE et al. [19,20].

Technical Limitations: The resolution and depth penetration of photoacoustic imaging need to be optimized for dental applications.

Clinical Integration: The technology needs to be integrated into clinical practice, which involves addressing regulatory, cost, and training issues.

Standardization: Establishing standardized protocols for imaging and interpretation in periodontal practice is essential for widespread adoption.

On overcoming all these limitations, PAI will make the periodontal diagnosis even more precised with real time instant assessment. Thus paving way for accurate ,on time diagnosis and appropriate treatment plan to enhance patient's valuable healthier life.

Conclusion

To maximize the potential of photoacoustic imaging in periodontal pocket measurement, further research and development are necessary. This includes improving the technology's resolution and depth penetration, reducing costs, establishing standardized protocols, and enhancing training for practitioners. Addressing these challenges

will be crucial for integrating photoacoustic imaging into routine clinical practice and fully realizing its benefits in periodontology.

In summary, while photoacoustic imaging offers promising advancements in periodontal pocket measurement, its successful integration into periodontal care will depend on overcoming existing limitations and validating its clinical utility through further research and development.

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