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PHOTOACOUSTIC IMAGING TOMOGRAPHY – A NOVEL NON-INVASIVE TECHNIQUE FOR MONITORING PERIODONTAL HEALTH

Periodontology

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ABSTRACT

This review aims to provide with an overview on photoacoustic imaging tomography for accurate evaluation of periodontal pocket dimensions. This modality effectively combines optical contrast with high resolution in-depth ultrasound imaging. Photoacoustic imaging benefits from the advantages of pure optical or ultrasound imaging, without the major disadvantages of each technique. It provides detailed 3-D information of the periodontal pocket morphology and extent of its soft issue base which may improve diagnosis by guiding the use of periodontal probes. This additional volumetric information may improve the treatment planning and help patients visualize their own inflammatory disease burden in 3-D. Therapeutically, this may increase the efficiency of treatment by mapping the pocket boundaries.

KEYWORDS

Photoacoustic imaging tomography, periodontitis, periodontal health, diagnostic tool.

INTRODUCTION:

The current metrics for monitoring periodontal health include attachment level, probing depth, bone loss, mobility, recession, and degree of inflammation[7]. The periodontal probe is the primary diagnostic tool which is used to detect the presence of periodontal pockets as measured from the gingival margin to the base of the crevice and the loss of attachment as measured from the cemento-enamel junction to the base of the crevice. The measurements recorded by the probe will depend upon the probing pressure used, the size of the probe tip, the angulation of the probe, the presence of subgingival deposits and, most importantly, the presence or absence of inflammation in the tissues[1].

Despite these limitations, manual probing is still the standard of care for periodontal diagnostics globally. However, it is becoming increasingly clear that this technology needs to be updated to be compatible with the digital technologies that could be utilized for accurate evaluation of periodontal pocket dimensions.

Photoacoustic imaging is a hybrid biomedical imaging technology that combines visible and near infrared excitation with acoustic detection. It extends the utility of ultrasound by enabling contrast based on optical absorption[9]. Traditional ultrasound operates under the principle of "sound in, sound out", but photoacoustic imaging shifts this concept to "light in, sound out"[10].

Photoacoustic imaging benefits from the advantages of pure optical or ultrasound imaging, without the major disadvantages of each technique. This imaging modality is based on the photoacoustic effect that was first observed by Alexander G Bell in 1880[2].

In photoacoustic imaging, absorption of optical energy from either an endogenous chromophore such as haemoglobin, melanin or lipids, or exogenous contrast agents such as organic dyes, gives rise to thermoplastic expansion and generation of acoustic (ultrasound) waves. These ultrasound waves can be detected and converted to electric signals then processed for imaging[3].

PRINCIPLE OF PHOTOACOUSTIC EFFECT:

The photoacoustic effect explains how electromagnetic energy can be absorbed and converted into acoustic waves. Photoacoustic tomography combines the high contrast from absorption of light with the high resolution and penetration depth of ultrasound imaging.

The basic idea of the photoacoustic effect is simple. A near infrared laser is incident on light absorbing target. This target absorbs a fraction of the incident energy and undergoes spatially confined heating. The temperature rise leads to thermoelastic expansion of the object. This sudden pressure rise generates wideband acoustic waves that can be detected with ultrasound transducers for image generation. By detecting the pressure waves, we can localize their source (i.e., where light was absorbed) and obtain important information about the studied sample. This is schematized in figure 1.

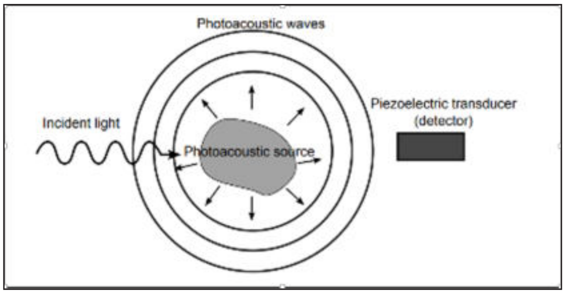

Fig.1: Basic Principle Of The Photoacoustic Effect

ADVANTAGES:

Photoacoustic imaging can provide high-resolution images (as low as 5 μm) with a deeper imaging depth than optical tomography due to the lower scattering of ultrasonic waves than light in tissue. Photoacoustic imaging has improved tissue contrast than ultrasound imaging. This is attributed to the rich endogenous and exogenous optical contrasts achieved by photoacoustic while ultrasound imaging is restricted by the mechanical properties of the tissues. Another advantage of photoacoustic imaging is the absence of ionizing radiation. Moreover, photoacoustic imaging has been shown to be faster than magnetic resonance imaging[4]. Additionally, the surfaces of hard tissues such as bone[13] and teeth[14] can be imaged. Photoacoustic imaging technique is highly reproducible with relative standard deviations of 10%[15]. This precision offers a major improvement over the Williams probe, which can only record integer values for pocket depths and has inter-operator error of up to 40%[16].

LIMITATIONS:

The penetration of photoacoustic waves is limited to approximately 5 cm in tissue due to optical attenuation[17]. The emitted ultrasound waves are strongly reflected from gas-liquid or gas-solid interfaces and cannot pass through gas cavities efficiently. Moreover, thick bones like human skull have been shown to attenuate and distort greatly the ultrasound signals[5]. The evidence for absorption and scattering of optical energy and ultrasound waves by bone suggests the limitations of this technology, particularly for imaging intrabony pockets and interproximal pockets. The presence of dental restorations may also generate background that affects photoacoustic waves. Moreover, gingival crevicular fluid pressure may prevent complete penetration into the pocket by squid ink-based contrast[6]

CLINICAL APPPLICATIONS:

The clinical applications of photoacoustic imaging are growing; some recent examples include endogenous imaging of inflammatory arthritis, non-invasive assessment of Crohn's Disease, and diagnosis of vascular malformations[11].

Lin *et al* (2018) showed the feasibility of periodontal pocket depth measurements utilizing photoacoustic imaging. In this study, they created artificial periodontal pockets with scalpels applied parallel to the tooth down to alveolar bone in pig jaw models. These artificial pockets were then loaded with food-grade cuttlefish ink as a contrast medium. They compared the pocket depth measurements obtained by photoacoustic imaging to those measured by gold standard periodontal probing method. They found that photoacoustic imaging could visualize the entire pocket with 0.01 mm precision. It was suggested that photoacoustic imaging could be a non-invasive diagnostic tool for periodontal pocket imaging and depth measurements. Since, they used only pig jaw models thus the created periodontal pocket may not truly mimic the in vivo conditions in humans.

Moore C *et al* (2018) reported the first application of photoacoustic imaging for monitoring dental and periodontal health in humans by using a food-grade contrast agent. The overview of the imaging setup used in this study is shown in figure 2. The PA-US transducer was connected to a stepper motor for axial scanning and a sliding positioner for lateral control—these components were attached to a larger frame for general positioning. The head immobilizer (cross-section shown) rested on a flat surface. They stated that this technique is ideal for imaging periodontal pockets, gingival soft tissue and thickness, and the surfaces of teeth. These features could be distinguished both by visual inspection— ultrasound signal from tooth is brighter than tissue — and more quantitatively with line profiles of photoacoustic and ultrasound pixel intensities. They also concluded that a 40 MHz ultrasound frequency provided sufficient resolution for discerning these features without sacrificing the requisite penetration depth. The imaging procedure took roughly 5 minutes per tooth but could be greatly improved with a mouthpiece transducer capable of scanning all teeth at once. It was common for the agent to coat the majority of the tooth surface even when it was locally administered to the gingival margin; however, this did not adversely affect measurements. They observed that contrast agent could be easily removed from the gingival sulcus after imaging. The flow of contrast agent into the gingival sulcus allowed the imaging and measurement of pocket depths, eliminating the need for probing. In the case of patients with peri-implantitis, this technique has potential to allow pocket depth measurements when physical probing is risky or impossible due to threading along the implant surface and tissue sensitivity.

Fig.2: Overview Of The Imaging Setup

CONCLUSIONS

There are limited reports of photoacoustic in dentistry, including implant characterization (Lee *et al,* 2017) and caries identification (Cheng *et al*, 2016). Smaller LED-based systems have recently been created with logarithmic reductions in cost and complexity. These innovations will likely make photoacoustic imaging more accessible to the dental community.

New technologies are now at the forefront with the potential for accurate, reproducible and volumetric digital measurements of periodontal pockets. These technologies are needed for comprehensive treatment planning and to assess outcomes of therapy. Moreover, periodontal pockets and their contents exert a burden on the host immune system and negatively affect overall health. Thus, pockets should be digitally mapped, in 3-D, and monitored as an important outcome of therapy and for the overall health of the patient. We envision that 3-D imaging would be supplementary to periodontal probing. Detailed 3-D information of the periodontal pocket morphology and extent of its soft issue base may improve diagnosis directly or indirectly by guiding the use of periodontal probes. This additional volumetric information may improve the treatment planning and help patients visualize their own inflammatory disease burden in 3-D. Therapeutically, this may increase the efficiency of treatment by mapping the pocket boundaries.

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