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Introduction

Special Issue on Lasers in Dentistry

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A quiet revolution is taking place in dentistry through the progression and integration of wide-ranging biophotonics technologies into clinical practice and research. These advances can be broadly divided into three major areas: Diagnostics, Therapy and Device Design/Manufacturing. Given our current emphasis on precision dentistry, biophotonics-based approaches are very attractive, enabling tissue interrogation at levels ranging from structural to molecular, and therapies providing selective and individualized treatment options. One of the major advantages of light-based diagnosis is its capability for non-invasive and real-time *in vivo* assessment that is quick and has no harmful side-effects. This translates into a capability for improved and easier diagnosis and monitoring as defined by clinical need. Combinatorial approaches that include both therapy and diagnostics, termed *Theranostics,* can provide many benefits to patient and clinician alike. Therapeutic uses of various biophotonics sources, especially LED arrays and lasers, span surgical and non-surgical realms in medicine and dentistry. Moreover, the often quoted 10 year lag between ground-breaking laboratory research and clinical practice is mitigated in this particular field by the power of social media, accessible scientific meetings and fora, as well as online learning and training avenues. This special issue is dedicated to highlighting a few of the key advances in biophotonics that hold considerable promise for improving patient care in dentistry.

One of the early domains of laser use in dentistry was caries detection and ablation. Current caries assessment techniques include Quantitative fluorescence, Laser-induced fluorescence (LF), transillumination and optical coherence tomography (OCT). In a paper by Wilder-Smith *et al*. that is included this issue, the clinical efficacy of LF and OCT was compared with current standards of care—visual examination and radiographs—for caries detection. The authors note that, although LF was most effective at detecting surface caries on smooth tooth areas, OCT provided a viable alternative to radiographs at multiple sites, including smooth surfaces, the margins of existing restorations and beneath sealants and restorations. However, the authors note that current swept-source OCT techniques are limited to detecting caries less than 2 mm below the tooth surface. Addressing this specifically in another paper included in this issue, Fried *et al*. utilized polarization-sensitive illumination and cross-correlation analyses which they term cross-polarization optical coherence tomography (CP-OCT). The authors demonstrated in a clinical study that CP-OCT can be used to monitor changes in the internal structure of early active carious lesions on smooth enamel surfaces. They also reported that this technique can be used to assess topical interventions with fluorides to reverse early carious lesions. These innovations clearly hold much promise to current restorative and pediatric dental practice.

The very first dental hard tissue laser showed considerable—if somewhat slow—ablation effectiveness *in vitro*[1]. However, these early devices frequently caused considerable increases in intra-pulpal temperatures, often leading to irreversible pulpal damage. This effect considerably impeded the adoption of lasers to clinical dentistry [2]. Since those early days, the development of a better understanding of laser-tissues interactions and improved optics and photonics technologies have provided avenues to overcoming this challenge. Innovations in precision machining at the nanoscale level, facilitated by extreme peak powers with pulsed beams that minimize collateral thermal damage have provided the basis for the development of safer and more efficient dental hard tissue lasers. Ongoing areas of innovation to improve clinical performance include new wavelengths and shorter pulse durations—potentially extending beyond the existing femtosecond ranges. The search for additional wavelengths has the goal of better achieving targeted clinical effects while avoiding adverse biological responses. This issue includes a paper by Yuichi Izumi *et al*. that describes one such innovation. It showcases the development of a new dental hard tissue laser operating at 2.76–3.00 μm wavelength from a solid state, chromium-doped

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cadmium-selenide (Cr:CdSe) active medium. Operating in nanosecond pulsed mode, this laser appears to cause only minimal heating in tooth substance, suggesting that there may be little need for additional cooling during laser tooth ablation. The potential for dispensing with a separate cooling mechanism may translate into ground-breaking improvements in clinical practice, including better visibility and improved cutting comfort, efficiency, and speed.

Existing clinical dental lasers such as Nd:YAG (1,064 nm), Er:YAG (2,940 nm), Er,Cr:YSGG (2,780 nm), Er:YSGG (2,790 nm) and CO_2 (9,400 and 10,600 nm) devices are all used for dental hard tissue excavation and recontouring. An additional feature of these lasers is their ability to modify the tooth surface for effective micromechanical interfacing with restorative materials. Two papers in this issue address these specific applications within separate contexts. Min-Le Chen *et al*. demonstrated that Er:YAG laser etching of the enamel surface significantly increased the adhesion of glass ionomer restorations as measured by shear-bond strength compared to conventional bur preparation and phosphoric acid etching. Although the authors performed *in vitro* thermocycling studies to evaluate performance during oral functionality, they indicate further *in vivo* testing is warranted prior to adopting this technique for routine clinical care. In another study, Manoel Sousa-Neto *et al*. demonstrated that a similar strategy of preparing radicular dentin surfaces with an Er,Cr:YSGG laser resulted in increased restoration-dentin bond strength of an epoxy resin-based root sealant. The results from this study suggest that combining a laser etching protocol with 17% EDTAC irrigation may improve root sealant retention.

It is a startling and little-known fact that two oral diseases, tooth decay (caries), and gum disease (periodontitis), constitute the most common human disease globally [3]. Moreover, it is increasingly recognized that oral health directly affects general health. Well-established oral-systemic connections have been noted in many conditions including diabetes, pre-term pregnancy, respiratory disease, and cardiovascular conditions including atherosclerosis [4]. Direct microbial dissemination from oral sites into the systemic circulation as well as a general, chronic inflammatory state triggered by untreated oral diseases have been implicated as causal agents. A study by Georgios Romanos *et al*. in this issue builds on these correlations by demonstrating that effective non-surgical anti-infective treatment with an Nd:YAG laser can reduce serum disease markers such as interleukin-1beta (IL-1β) and matrix metalloproteinase-9 (MMP-9). This study underscores the tenet that improving oral health should be a basic component of broader medical health management strategies.

The laser used in the Romanos study was employed primarily as a curettage and disinfection tool. There is growing realization that the lower fluences which interact with peri-treatment areas can exercise potent bystander effects including immunomodulation and healing-regeneration promoting benefits [5]. Applying exogenous dyes to enhance the selective effects of light in tissues, for example in tumors and in biofilm, is the central tenet of Photodynamic therapy (PDT). Advantages of this approach to antimicrobial disinfection include controlled and localized bactericidal effects, and an avoidance of antimicrobial resistance mechanisms to date [6]. Two papers in this issue address this topic. Casarin *et al*. investigated the outcomes of scaling and root planing combined with methylene blue-based antimicrobial PDT in periodontal pockets. The investigators report an improvement in clinical disease parameters as well as reduced microbial burden, specifically the organism *Actinobacillus actinomycetemcomitans*. They conclude by recommending the addition of PDT techniques to routine periodontal disease management. In another study by Thomas Mang *et al*., the use of a purpurin-based photosensitizer considerably reduced biofilm contamination of routinely used dental materials such as titanium, glass and dental acrylic. The PDT treatments caused mechanical embrittlement of the microbial biofilm, enabling its removal with simple water jet irrigation. Thus, light-based approaches offer a range of opportunities for microbial control to improve oral and systemic health.

Existing techniques for endodontic root canal preparation that aim to achieve a clean, smear-free dentine surface include direct mechanical cleansing, antibacterial rinses and inserts, and PDT-based techniques. A novel approach relies on the photoacoustic, agitation-based disinfection process termed Photon-induced Photoacoustic Streaming (PIPS), which was found to aid root canal preparation in early studies [7,8]. In this issue, Anja Barbara *et al*. present a study in which the investigators were not able to determine any additional effect of laser PIPS on the bond strengths of a root canal sealant material to root canal dentin cleansed conventionally using 7% EDTA treatment. Thus, further studies are necessary to gain a better understanding of the variables that affect the outcomes of light-based techniques in endodontic treatments.

One particularly exciting application of lasers is its non-surgical use at low doses to alleviate pain or inflammation and promote tissue healing and regeneration. This specific application was formally called Low level light/laser therapy (LLLT) but has now been renamed Photobiomodulation (PBM) therapy to most accurately describe its multifaceted biological effects. Three studies in this special issue focus on the broad applications of PBM therapy. Among these, the first clinical study by Zekeriya *et al*. demonstrated that PBM therapy was able to improve the stability of a mini-screw placed as anchorage for orthodontic tooth movement. However, Interleukin-1β presence in gingival crevicular fluid around the tooth or implant was not affected by PBM. The observations in this study support prior contentions of improved implant osseointegration as well as the potential for accelerated orthodontic tooth movement.

In order to elucidate the effects of PBM on soft tissue, Josimeri Hebling *et al*. used an *in vitro* model of gingival fibroblasts challenged by a cocktail of the inflammatory cytokines TNFα, IL-1β, IL-6, and IL-8 to simulate mucositis. They noted that PBM therapy was able to promote proliferation and migration while modulating matrix synthesis (Collagen 1), reporting increased nitric oxide presence in a dose dependent manner. This is an important observation, as nitric oxide is one of the key molecular mechanistic components of PBM treatment [9]. Another study by Yuichi Izumi *et al*. identified improved epithelial and bone wound healing in extraction sockets in a rodent model treated with PBM therapy. Interestingly, the authors used a non-conventional treatment protocol, applying a high frequency pulsed diode laser at high irradiances to achieve the desired therapeutic benefits. This work provides a strong basis for future studies using specific PBM protocols to establish optimal therapies tailored for defined healing and regeneration effects in oral-dental tissues.

In conclusion, it is our hope that this special issue serves to showcase the tremendous progress and excitement that is driving the field of lasers in dentistry. Biophotonic technologies and approaches are indeed progressing rapidly towards the practical reality of a multifunctional "light" device with multiple wavelengths to meet every clinical need, echoing the vision described by Pick and Powell in 1993 [10].

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