

Dental Medicine and Engineering Unite to Transform Oral Health Innovations

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H. Koo^{1,2} and K. Stebe^{2,3}

Abstract

This perspective article urges the academic community to adopt a coordinated approach uniting dental medicine and engineering to support research, training, and entrepreneurship to address the unmet needs and spur oral health care innovations. We describe a new interschool institute that brings together dentists, scientists and engineers, resources, and a training program dedicated for affordable oral health care innovations, which may serve as a template for dental medicine–engineering integration.

Keywords: bioengineering, microbiome, tissue regeneration, nanotechnology, personalized medicine, oral–systemic disease(s)

We urge the academic community to adopt a coordinated approach to support research, training, and entrepreneurship through joint programs and institutes that unite dental and engineering schools. The need for new approaches to address oral–craniofacial disorders is clear and urgent. The prevalence of untreated oral diseases worldwide has grown to affect an estimated 3.5 billion people. Globally, oral diseases represent the most prevalent health problem, with 1 billion more cases than those of cardiovascular and chronic respiratory diseases, diabetes, and cancers combined, inflicting an enormous economic burden of US\$390 billion (NIH 2021; WHO 2022). These numbers are staggering, and solutions are urgently needed. Novel engineering approaches can yield new paradigms to reveal disease mechanism, strategies for disease prevention and mitigation, and approaches for affordable and personalized diagnostic tools and therapies for broad ranges of oral health challenges.

In January 2021, the University of Pennsylvania established the Center for Innovation & Precision Dentistry (CiPD), an institute that unites dental and engineering experts, resources, and facilities to promote cross-disciplinary research, training the next-generation innovators and entrepreneurs dedicated for affordable oral health care innovations (Baillie 2021; Penn Today 2021; NIDCR 2021). The structure, focus, and activities of our institute can serve as a template for dental medicine–engineering integration. The CiPD draws co–founding directors (Koo and Stebe) from dental medicine and engineering. The co-directors continually build the CiPD community to create a network of research partners and to generate support for center activities. The institute has broad thematic boundaries to allow flexibility in promoting collaborations and training opportunities that address unmet needs. To advance this mission, we are supported by institutional funds, industry sponsorship, and federal grants, including a dedicated National

Institute of Dental and Craniofacial Research (NIDCR)–supported training program at the interface of engineering and oral–craniofacial sciences (NIDCR 2021).

Promoting Unique Collaborative Research and Supporting Translation

Seed grants for engineering/oral health scientist teams and cross-disciplinary workshops/symposia are vital to spur collaboration. CiPD hosts an annual symposium where engineers, clinicians, and scientists unite to define opportunities to advance oral health innovation at the intersection of dental medicine and engineering. CiPD seed funds are awarded to engineering/oral health faculty teams to spawn new federally funded collaborations and to support inventors as they develop concepts for translation. Partnerships with existing centers and institutes amplify our impact. In partnership with Penn Center for Health, Devices and Technology, the CiPD sponsors the Innovation in Dental Medicine and Engineering to Advance Oral Health (IDEA) Prize to seed engineering/oral health collaborations for the development of new cost-effective diagnostic and therapeutic approaches. In collaboration with the Institute for Biomedical Informatics, the CiPD provides funds

¹School of Dental Medicine, University of Pennsylvania, Philadelphia, PA, USA

²Center for Innovation & Precision Dentistry, University of Pennsylvania, Philadelphia, PA, USA

³School of Engineering and Applied Sciences, University of Pennsylvania, Philadelphia, PA, USA

Corresponding Author:

H. Koo, School of Dental Medicine, University of Pennsylvania, 240 South 40th Street, Levy Bldg., Philadelphia, PA 19104-6030, USA.
Email: koohy@upenn.edu

to leverage artificial intelligence to analyze big data to predict diseases, assess the effectiveness of existing therapies, and identify new approaches by integrating omics and clinical data with electronic health records. Industry partnerships have led to fellowships to support trainees in dental–engineering research, and a partnership with the American Association for Dental, Oral, and Craniofacial Research (AADO CR) has resulted in new opportunities to engage engineers’ participation. For example, CiPD/Colgate–Palmolive Fellows focus on new technologies to study and promote children’s oral health.

Our efforts are generating affordable and translatable approaches, including ultra-sensitive portable technologies for pathogen detection in saliva, Food and Drug Administration (FDA)–approved nanoparticles that target biofilms in severe caries, and high-precision microrobotics for biofilm disruption and lipid nanoparticle technologies for messenger RNA (mRNA) delivery (leveraged from the COVID-19 mRNA vaccine) to treat oral cancer (Hwang et al. 2019; Chen et al. 2021; Liu et al. 2021; Babeer et al. 2022). Discoveries related to the microbiome and host immunity are revealing relationships among systemic diseases, suggesting new, personalized treatments and individualizing oral health care (Teles et al. 2021; Bostanci and Belibasakis 2023). Cosponsored efforts are also yielding fruit; the IDEA Prize awarded to low-cost plant–chloroplast biotechnology for scalable therapeutic enzymes/protein production has created a feasible way to prevent oral SARS-CoV-2 transmission and dental plaque in a consumer-friendly chewing gum delivery system (Singh et al. 2021; Daniell et al. 2022). This system is now proceeding to phase 2 clinical trials following investigational new drug (IND) approval by the FDA. These initial successes exemplify the opportunity for transformative innovations.

Training Tomorrow’s Researchers and Innovators

Cadres of researchers who leverage engineering approaches in oral health care are crucial to the success of this vision. Dentist-scientists must be trained to apply engineering approaches, and engineers must be educated in oral and craniofacial sciences to address knowledge gaps and unmet needs, as well as communicate effectively while understanding the technical/clinical limitations and hurdles to develop feasible diagnostics or therapeutic solutions. To meet this need, the CiPD has launched a training initiative for postdoctoral researchers drawn from both disciplines.

Under the National Institutes of Health/National Institute of Dental and Craniofacial Research (NIH/NIDCR)–supported postdoctoral training program “Advanced Training at the Interface of Engineering and Oral–Craniofacial Sciences,” we are developing a cross-disciplinary workforce of dentist-scientists and engineers (NIDCR 2021). This funding, augmented by fellowships from industry, university-wide partnerships, and diversity initiatives, supports a community of postdoctoral scholars focused on applying cutting-edge engineering approaches to address oral health needs. All CiPD postdoctoral researchers are co-mentored by dental and engineering faculty, are provided with tailored training in their subdisciplines, and

receive expert guidance from a cross-disciplinary career mentoring committee that includes faculty members in engineering and dental medicine, including those in clinical practice. Under this highly tailored program, trainees advance their research, submit NIDCR grants, and compete for positions to develop careers in advancing precision and affordable oral health care. Furthermore, our postdoctoral scholars interact regularly with industry and avail themselves of the mentorship and acculturation provided by the AADO CR and other professional organizations. We highlight the interactions between CiPD participants and the AADO CR MIND-the-Future program aimed at increasing diversity in the field through the joint training of minority early career investigators.

We are focused on emerging engineering areas, including robotics, nano/biotechnology, artificial intelligence, mRNA/drug delivery, organ-on-a-chip, and advanced materials applied to biofilm microbiome, host immunity, and tissue regeneration. New knowledge developed in these domains supports strategies for disease prevention and mitigation in susceptible populations, and the development of precision diagnostics, new preventive approaches, and affordable therapies for dental caries, periodontal diseases, and oral cancers. All become aware of product development hurdles and regulatory requirements to safely bring new approaches from bench to patients and achieve public health benefit. To promote this mission, CiPD coordinates recruitment of junior faculty talents through joint dental–engineering appointments.

Entrepreneurship is critical to advance oral health care innovations. Through integration with the university’s intellectual property and commercialization, venture capital, and foundations, we are building an ecosystem to facilitate translation and commercialization from prototyping and market evaluation to product development and fundraising for trainees and faculty (Baillie 2021; Penn Today 2021; NIDCR 2021).

Growing a Global Dental Medicine–Engineering Community

To sustain the nascent dental medicine–engineering ecosystem, further growth, support, and integration are needed. At the University of Pennsylvania, our initial efforts in building and training a community of researchers, innovators, and practitioners are generating a new cadre of experts equipped to bridge engineering and dental medicine to develop new research thrusts and to translate discoveries that are affordable and accessible to address health disparities and improve patient care. The development of cross-trained talent at predoctoral and doctoral levels will provide a pipeline for postdoctoral and faculty recruitment. Importantly, established programs in tissue regeneration and clinical translation (e.g., Michigan–Pittsburgh–Wyss–Regenerative Medicine [Taylor et al. 2021] and UCSF–UCSF/Berkeley/Davis/UCLA–Stanford [C-DOCTOR 2016]) and new oral health/engineering doctoral training programs are developing nationwide (e.g., Columbia Dental–Engineering PhD program [Columbia University 2023]). In parallel, initiatives from NIH/NIDCR (SBIR–STTR, academic–industry partnership), CareQuest Institute for Oral Health (2021), and

Forsyth (2021) to promote partnerships in oral health technologies can facilitate entrepreneurship and accelerate innovation. Similar initiatives are developing worldwide. Support for and integration among such programs in the form of cross-disciplinary funding initiatives, joint symposia at national/international meetings, and dual-degree programs with engineering, institutional startup programs, and integration between dental and engineering societies will allow these seeds to flourish and bring urgently needed innovations to oral health care.

Author Contributions

H. Koo, K. Stebe, contributed to conception and design, data interpretation, drafted and critically revised the manuscript. All authors gave final approval and agree to be accountable for all aspects of the work.

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