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Re-architecting Oral Healthcare for the 21st Century

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Abstract

The convergent forces of rising costs, growing consumerism, expensive new treatments, sociodemographic shifts and increasing health disparities are exerting intense and unsustainable pressures on healthcare systems. As with the other health domains, these disruptive forces demand new approaches and delivery models for oral healthcare. Technological innovations and practices borrowed from the e-commerce and tech sectors could facilitate the move to a sustainable 21st century oral healthcare system, one that delivers high-quality, value-based care to wider groups of patients. The broad reach of mobile technologies and changing digital lifestyles *provide unique opportunities for using remote monitoring and* self-care tools to reinforce preventive oral hygiene behaviours. By leveraging big data analytics and insights gleaned from the use of sensor-enabled oral care devices, providers will be able to engage patients more effectively and deliver timely, personalized behavioural nudges to support optimal oral health. Dental insurers and payers will need to reinvent their business models to incentivize dental providers and patients who embrace the digital-dentistry paradigm. This could involve increasing reimbursements for mHealth-delivered preventive dental services and holding individuals accountable for behaviours that put them at higher risk for dental disease. While Dentistry 1.0 was defined largely by the treatment of established dental disease, Dentistry 2.0 portends a new era of patient-centric, technology-enabled, outcomes-driven, and prevention-focused oral healthcare delivery with significant individual, provider and societal benefits.

Keywords

Digital dentistry; mHealth; big data; health behaviours; personalized interventions

Introduction

A confluence of economic, demographic and technological trends is fundamentally reshaping the landscape of healthcare in general, and oral healthcare in particular. With

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healthcare costs far outpacing economic growth and with aging societies and fiscal crises increasingly straining healthcare funding, conversations about the social and economic determinants of “who pays” and “how” are becoming increasingly prominent [1] [2]. The steep trajectory of health expenditures in advanced economies is illustrated by the outlays for dental services in the United States over the past several decades. Spending for dental care increased from approximately \$2 billion in 1960 to \$117.5 billion in 2015 [3] [4]; an average annual increase of 7.7 percent that greatly surpassed the average inflation and economic growth rates for that period. The unrelenting upward pressures in dental care spending have forced policy makers and payers to call for fundamental changes to oral healthcare delivery and seek alternate approaches to the increasingly unsustainable fee-for-service model. Additionally, as the numbers of dentally uninsured individuals grow and the out-of-pocket costs of dental care become more and more unaffordable, patients are likely to limit their use of dental services and even skip necessary care [5]. Clearly, the changing realities require a re-architecting of the conventional dental care paradigm. We need innovative and sustainable models of care delivery that will allow patients to receive the best oral healthcare at the lowest cost while ensuring that providers are equitably reimbursed and incentivized.

One appealing strategy is the embrace of digital innovation to improve the quality, efficiency and value of dental services. We live in a world where digital is no longer something new and exciting but is commonplace and interwoven into the fabric of our daily lives. In this digital world, companies like Amazon and Google have shown how the pervasive internet, ever-denser connectivity, big data analytics and artificial intelligence can be used to dissolve longstanding boundaries and constraints, build closer relationships with customers, learn more about their behaviours and preferences, and deliver highly personalized experiences and products in sustainable and cost-effective ways. Importantly, the digital ecosystems have allowed companies to create and capture new value through increasingly sophisticated data analytics and delivery models while fostering scalable collaborations between previously siloed stakeholders. Many of these technological developments are being used to optimize healthcare in new and exciting ways. They contain opportunities for the dental community to develop more efficient ways to deliver cost-effective but high quality dental care to a broader gamut of patients, and ultimately, increase the value proposition of dentistry. Reimagining the delivery of oral healthcare within the evolving digital world requires a considered appraisal of key trends reshaping the healthcare landscape.

Proliferation of the digital natives

Digital technologies have fundamentally changed the ways in which we communicate, shop, travel or play. Exposed to the seamless experiences offered by platforms such as Uber, Amazon or AirBnB, empowered consumers are applying their heightened expectations to every brand and industry. It seems reasonable that individuals who have come to expect a personalized, on-demand experience would eventually come to want the same for their healthcare. The greatest expression of this health consumerism will come from millennials who have grown up entirely in a digital world and more likely to research health issues online, share information on health providers via social media and participate in self-management of their health [6] [7]. As these digital natives assume more of the financial

burden of their dental care and seek value and better outcomes, the locus of control will shift from provider to patient. Dental care providers and payers will have to pay closer attention to creating patient experiences that match the consumer expectations of these digital natives. This means seamless and personalized interactions; greater transparency in costs, comparative effectiveness of services and value for money; a social media strategy; and a digital outreach to engender patient awareness and loyalty. The influx of wearables and other self-monitoring technologies (e.g. FitBit, Apple watch) is creating a whole generation of “self-tracking” enthusiasts driven by the idea that collecting and analysing detailed data about daily activities can help them improve their quality of life and deal with any medical problems [8]. These socio-digital developments require dental providers to begin thinking about how they will leverage digital technologies to help patients become engaged in their own oral healthcare and develop preventive efforts that extend beyond the confines of the dental office.

Growing emphasis on Health Behaviours

Over 75% of the healthcare spending in advanced economies is directed to the management of the health consequences of poor lifestyle choices [9]. Modifiable health risk behaviours, such as poor diet, lack of physical activity, smoking and overuse of alcohol, are key contributors to the development and progression of chronic diseases including type 2 diabetes, cardiovascular disease, stroke, and chronic lung disease. Unless health systems can find effective ways to get people to adopt healthier behaviours and emphasize prevention over disease management and treatment, any efforts to curb healthcare costs and improve care quality and delivery are bound to fail. The issue of preventive behaviours is pertinent to dental disease which has strong behavioural antecedents and is closely linked to inadequate oral hygiene. There is considerable evidence that systematic, twice-a-day tooth brushing with a fluoridated toothpaste maintains oral health and decreases dental disease [10]; [11]; [12]. Yet, this basic behaviour is not as widely and fully practiced as dentists and health organizations would like [13]. Revealingly, Chadwick [14] found that a significant percentage of the population do not accomplish these daily tasks, with 33% of men brushing less than twice a day and 59% of women regularly skipping brushing at bedtime. Even brushing twice a day may be ineffectual; if the technique is not successful at removing dental plaque on all tooth surfaces, the functional value of tooth brushing is almost negligible [15]. All these studies emphasize the need to develop more relevant ways to inculcate and maintain ideal brushing behaviours. The customary economic model of oral health care, a reactive system that [16] mainly treats and manages dental disease after it is established, will need to be modernized by infusing more prevention and by integrating behaviour change as a core component of new care delivery models. Reflecting trends in general healthcare and personalized medicine, the dental community will find itself increasing its embrace of behaviourally-based, patient-centric approaches that complement and extend the traditional clinic-based care.

Engaging patients in self-care between clinic visits is a complementary theme that is being increasingly recognized as essential to improving health and improving patient satisfaction. Studies have demonstrated that patients with chronic disease who are actively engaged in their self-care have better health outcomes and live longer compared to control groups [17]

[16]. The putative results of *health-promoting self-care behaviours* are so compelling that Kish [18] argued that if patient engagement were a drug, it would be the blockbuster drug of the century and medical malpractice not to use it. Care delivery systems of the future will leverage behavioural strategies to render evidence-based oral care feedback and advice readily accessible to a diversity of patients with a broad range of needs and preferences. The trend to change patients from passive passengers to active drivers of their own oral care will gain momentum as insurers and payers increasingly shift to value-based reimbursement models. Patient engagement signals a shift for the existing paternalistic models of care, wherein clinicians direct their patients what to do (and often unsuccessfully as manifest by dental disease patterns), to collaborative arrangements where adjunctive systems and processes enable clinicians to educate their patients and sustain interest in their on-going care [19]. Extending oral healthcare outside of the clinical setting to support patients in their daily lives will help patients maintain their oral health long-term, reduce the likelihood of dental disease requiring costly restorative services and improve satisfaction with the dental care experience.

Addressing the challenge and opportunities presented by patient engagement will require borrowing from consumer science and behavioural economics techniques used by consumer retail companies, which have developed and perfected their ability to market and engage consumers. These techniques include micro segmentation (identifying very small groups of people with similar interests and behaviours) to identify opportunities to better understand the needs and interests of individual consumers. Micro-segmenting a population enables the identification of the “market-of-one,” where one can understand the needs, interests, and ways to influence behaviour of an individual person and improve their health and care. In one study, K-means clustering (to identify different population segments) and classification and regression trees (to find characteristics of each individual segment) were used to find groups of persons with common interests and target persons with personalized communication tailored to their needs and desires. This pilot used big data - both data internal to the health insurance company (claims, lab, pharmaceutical, health risk assessment, etc.), and external (exogenous) data outside of that normally used in healthcare such as household information, lifestyle and personal behaviour, and consumer purchases. All that data and advanced data science techniques could allow the health providers and payers to increase their ability to engage patients and change behaviour.

Penetration of Mobile Technologies into Healthcare

Digital technologies are fundamentally altering the ways in which healthcare is delivered and consumed. Recognizing the growing number of digital omnivores and the ubiquity of smartphones and wearables, healthcare systems and providers are finding ways to utilize mobile technologies for remotely measuring health and delivering healthcare and preventive health services (i.e., mobile health or mHealth). Newer mHealth technologies with embedded sensors require little attentional effort from the user and allow the unobtrusive collection of objective, high resolution data on “real world” health indicators and health behaviours [20] [21]. Merging granular information from multiple sensor streams offers a unique opportunity to develop sophisticated causal models of how a health-compromising behaviour truly occurs in naturalistic settings, what prompts it, what moderates it, and

ultimately, how the behavioural pattern can be disrupted in a sustained manner. The capabilities of mHealth have prompted the concomitant development of personalized healthcare delivery models that shift the responsibility for personal health away from payers and health systems towards the individuals. Increasingly, patients are encouraged and incentivized to be more active drivers of their own health instead of passive passengers abiding by episodic instructions from a care provider. By allowing individuals to conveniently track and manage everything from blood pressure to glucose in their native environments, the on-demand mHealth solutions seek to help individuals understand their health status and engage in preventive behaviours while being guided by personalized input from their care providers. Furthermore, the remote monitoring abilities of mHealth technologies allow providers to proactively identify those at risk for an adverse health event and intervene in a timely manner.

The application of mHealth approaches is particularly relevant to oral healthcare. Tooth brushing is a culturally ingrained and socially influenced health behaviour that is widely practiced. However, despite numerous educational efforts, the frequency and effectiveness of tooth brushing remain troublingly low. Patient non-adherence to tooth brushing techniques recommended by dental professionals is too often misunderstood, forgotten, or even completely ignored [22]. The variety of brushing techniques recommended by dentists and dental associations perpetuate the confusion among patients [23]. The large gap between quality oral hygiene routines (OHRs) and what is actually practiced by individuals is further perpetuated by the dentist's inability to monitor actual brushing behaviours in home settings. Unable to detect emerging non-adherence to prescribed OHRs, providers cannot provide timely support and corrective feedback. Newer mHealth-based technology platforms being developed allow unobtrusive, remote monitoring of tooth brushing behaviours in real-world settings and provide customized, titrated feedback. Utilizing commercially available electronic tooth brushes and/or smart watches as data collection devices, the Remote Oral Behaviours Assessment System (ROBAS) captures key details of tooth brushing behaviours (when used, for how long, pressure applied, dental quadrants covered) in the home setting. The ecologically-accurate data is collected and securely transmitted to a cloud server for subsequent analyses by appropriate statistical tools. Such a mHealth platform could serve as the basis of a scalable, interactive ecosystem that passively monitors OHRs, infers and predicts improper OHRs, and delivers engaging and timely personalized feedback to support quality OHRs by individuals.

Using mHealth technologies should be an essential component of patient engagement and self-management because it puts healthcare directly into patient hands. Moored in the digital world, mHealth's ability to remotely monitor and correct brushing behaviours could transform both the research and practice of dentistry. Currently, brushing and flossing behaviours are inferred by measuring traditional oral hygiene indicators (i.e., dental plaque, periodontal inflammation, caries) during a clinic visit. The clinical assessment is augmented by patient self-reports of their tooth brushing practices. However, self-reports are notoriously prone to recall and social desirability biases that distort data and inferences [24] [25] [26]. Also, the high frequency and low salience (i.e., there is nothing unusual or atypical to make them stand out) of tooth brushing activities make it difficult to recollect them accurately. The clinical assessments themselves are time and resource intensive and difficult to scale-up to

involve larger groups or populations, particularly those without regular access to dental services. In the dental context, low-touch mHealth systems could help clarify the precise relationships between tooth brushing behaviours captured in the home environment and the health outcome (i.e., plaque and dental disease) assessed in the dental setting. By leveraging mHealth's real-time monitoring and feedback capacities, dental providers would be better positioned to inculcate and enable long-term adherence to OHRs, and understand the determinants/predictors of why individuals do or do not engage in the prescribed OHRs. Empowered by mHealth systems, front-ended by OHR measurement and feed-back devices (i.e., electronic toothbrushes, smartphones) and back-ended by risk prediction and personalized intervention algorithms, digitally-engaged patients would exert more control of their own oral health while providers would be able to provide quality patient-centred and value-based care.

Big data and algorithmic healthcare

As the massive amounts of digital data generated by mobile technologies begin to merge with clinical, molecular and contextual data from thousands and millions of patients, the healthcare sector will have to confront the challenges and opportunities presented by the sheer volume, variety, and complexity of the big data [27]. Companies like Google and Amazon have shown how such mindboggling data can be gathered, crunched and used to enhance operational effectiveness, innovate, and generate new monetization opportunities. Every day, the internet giants screen and analyse billions of consumer queries and purchases to better understand the market and predict future user patterns. Much of the industrial-infrastructure and methods for collecting and handling large datasets could be adapted for developing new models of delivering value-based healthcare. The interconnectivity of datasets and data producers, joined by internet backbones, is particularly germane to dental care which is typically delivered within the confines of small individual practices. These data silos prevent providers and health systems from gaining unified views of dental practices and clinical outcomes and perpetuate increasingly archaic business models. In today's digitized economy, the ability to capture and analyse large data represents a real competitive advantage, one that dentistry can use as a catalyst to enhance and transform. The shift towards integrative digital and open data approaches is further promoted by the growing linkages between oral and general health and the integration of oral and general healthcare. Seamless data sharing arrangements between dental and medical providers would have a much better chance of identifying disease precursors and underlying conditions and facilitate the systematic coordination of health services. Clearly, dentistry will need to embrace the big data paradigm as a strategic asset if it is to continue to innovate, reinvent and evolve as a clinical specialty in a digital world.

Once the health data can be collected in a usable form, the next technological challenge is to extract the information contained and transform the raw data into knowledge and actionable clinical insights. Fortunately, as data has been getting bigger, our ability to transform and translate the data has also improved, and allowed us to move from reporting what has happened in the past (data reports or "descriptive analytics") to learning what is going to happen in the future (data science or "predictive analytics"). Here again, the disruption is driven by concomitant advances in computing power and analytic approaches. Newer

automated analytical approaches (e.g., machine learning) use computer-based algorithms to rapidly sift through millions of data points from individual-level observations to recognize patterns [28]. Utilizing an articulated framework of rules, the analytic systems learn to make connections between very dissimilar elements and infer meaningful relationships. What is significant is that the algorithms can “self-learn” and refine themselves as they process data from millions or tens of millions of individuals followed over time. The analytical capabilities are further buttressed by the computer’s ability to incessantly scour and learn from the daily deluge of new scientific literature and clinical trials information with *unparalleled* speed, accuracy and lack of bias. In the not so distant future, a large component of healthcare will be driven by algorithms that assimilate and process huge datasets to provide providers and payers with granular clinical, social and behavioural information on their patients [29]. Beyond promoting patient engagement and self-care, a data-based and algorithmically driven healthcare system will help realize the promise of personalized health while improving efficiency, reducing complexity and lowering costs.

Bridging the digital divide

Although mobile technologies hold great promise in empowering people and transforming healthcare delivery, they can potentially exacerbate the separation between those with or without access to these technologies or those who lack the awareness or skills to exploit these tools. The mHealth usability challenges are further compounded by a variety of challenges including data security and privacy concerns, interoperability and integration with existing IT systems as well as commensurate reimbursements. A 2015 WHO global survey revealed affordability, legal issues, evidence of cost-effectiveness and lack of legislation or regulation as key barriers to mHealth adoption [30]. Clear guidance and regulation could facilitate the adoption of digital health technologies. For example, including mHealth services and devices in dental practice guidelines could support their use especially if they are described in the context of existing therapies and treatments. Beyond digital literacy and affordability, the ability of digital approaches to improve oral health practices and self-care ultimately depends on patient adoption and sustained engagement. Patients need to be highly motivated to make changes in their oral health behaviors, praised and incentivized when they follow through, and provided timely feedback and guidance when they drift from best practices. For digital health products to make the transition from novel to necessity, we will need to develop patient-facing solutions that go beyond technology to utilize insights from disciplines as varied as economics, human-centered design, psychology, anthropology and moral philosophy [31]. Most importantly, the products have to create increasing value for the users, connecting patients, providers and health systems in a seamless continuum of care aimed at improving oral health at the individual and population level.

Oral healthcare in a digital world

So how can dentistry adapt and advance in the rapidly changing digital world? Most of the current conversations related to digital dentistry are reflective of the traditional dental delivery model and center on micro trends in technology-assisted restorative services (e.g., CAD/CAM), digital radiography and electronic patient records [32]. However, the trends

described above clearly indicate that the inevitable transformation of oral healthcare is being driven by macro-economic, social and technical influences from outside the dental profession. The emerging era of consumer-driven healthcare will require dentists to form and sustain relationships with their tech-savvy patients and use the reach and capabilities of digital technologies to stay connected with them between dental visits. Using a combination of mHealth devices, data science tools and behavioural strategies, dentists will have figure out ways to engage their patients and motivate them to be more active participants in their self-care. A growing emphasis on preventive oral health and personalized care will foster deployment of precision behavioural interventions that target the right individual, at the right time in the most effective way [33]. The growing consumerism, driven partly by higher out of pocket expenses, will lead patients to demand greater transparency on what they are getting for the money they spend on dental services{Citation}. Patients will come to expect ready access to information on the quality and cost of dental care and look for value and positive experiences as they choose their dental care providers.

Over the coming decade, the traditional economic incentives that have enabled “disease-centred” dental care models are likely to be replaced by alternate care models that emphasize prevention and maintenance of good oral health. Instead of being rewarded for the volume of care, dentists will increasingly deal with new value based-models of reimbursement that recognize and encourage cost-effective care and quality outcomes. Newer digital technologies, common data standards and changing patterns of disease will broaden the scope of dental practice and speed the integration of oral with general healthcare [34]. From health behaviour interventions to screening and monitoring of systemic diseases, dentists will find themselves working more closely with physicians and other care providers in delivering comprehensive healthcare. For example, customizable sensors contained within consumer devices or point of care biosensors will not only track tooth brushing behaviours and techniques, but also collect information on disease biomarkers manifesting in saliva [35]. Real time processing and analytics of the streamed data will provide actionable insights to patients, dentists, and physicians. Personalized feedback to patients will prompt them to modify behaviour/take action to improve health (brushing, take medications, etc.) while the feedback to the physician and/or dentist will allow them to monitor compliance and customize interventions. In some ways, dentists will function as data scientists and risk-managers, utilizing digital technologies and data science tools to monitor and manage the oral health of their patient populations. Cutting-edge technologies and sophisticated machine learning algorithms will allow dentists to proactively identify patients at high risk for dental disease by remotely monitoring errant brushing behaviours and implement timely preventive actions.

Insurance is a major determinant of how dental services are provided and utilized in certain countries. Dental insurers, payers or commissioners will need to reinvent their business models to incentivize dental providers and patients who embrace the digital-dentistry paradigm. Until now, insurers have been in the business of underwriting risk based largely on claims data provided by dental practitioners. With new mHealth and big data driven approaches, insurers would be able to go beyond pricing and underwriting risk to influencing and reducing risk as well, and doing so with a much better understanding of customers’ oral health behaviours and other risk factors. Insurance plans could serve as the

unifying data analytic hubs that link individual dental providers and patients and support them through real-time actionable health information and recommendations. The restructured insurance/commissioning models could involve increasing reimbursements for mHealth-delivered preventive services and holding individuals accountable for behaviours that put them at higher risk for dental disease. Driven by data analytics and a prevention focus, it is likely that part of the dental reimbursements will give way to capitated, risk-adjusted models. A lump-sum fee would cover the entire oral healthcare care of a patient on a yearly basis and is augmented by traditional fee-for-service for dental procedures.

Clearly, technological advances, and the accompanying sociocultural developments, are profoundly changing the context within which oral healthcare is being delivered. The inevitable transformations require dentistry to be proactive about responding to the disruptive pressures and strategic about leveraging the contained opportunities to create additional value for the patient, provider and society. Embracing the rapidly evolving digital capabilities, in particular, will determine the specialty's ability to thrive and create additional value in exciting and meaningful ways. The intersection of digital technologies, remote patient monitoring, big data analytics and personalized patient engagement strategies have the potential to improve oral health and reduce unnecessary costs at both individual and population levels. While Dentistry 1.0 was defined largely by the treatment of established dental disease, Dentistry 2.0 portends a new era of patient-centric, technology-enabled, outcomes-driven, and prevention-focused oral healthcare delivery with significant individual, provider and societal benefits.

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