Digital dentistry: A solution to the dentistry crisis?

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7 Digital dentistry

A solution to the dentistry crisis?

Anthony Larsson and Dominika Sabolová

1 Introduction

The concept of digital dentistry pertains to the dental technologies used to incorporate digital, or digitally controlled, components to perform dental procedures as opposed to using mechanical or electrical tools (Ito, Hamid and Ichikawa, 2016). The purpose of using digital dentistry is that it is more efficient than mechanical tools in conducting dental procedures. This applies to restorative as well as diagnostic purposes. Digital dentistry was developed as a means of meeting the increasing demands among patients for a faster, more secure, and more conformable experience. Digital dentistry has also been developed as a means of dealing with the shortage of resources in primary care. For instance, in the United States, this primary care shortage has led to an increased need to improve health care by increasing the utilization of existing health care providers (Giddon et al., 2013). Specifically, Petterson et al. (2012) forecast that the United States will require approximately 52,000 more primary care doctors by 2025, of which the majority (33,000) are required due to population growth. Other factors such as aging and insurance expansion will require an additional 10,000 and 8000, respectively (Fodeman and Factor, 2015). Needless to say, this creates an unsustainable situation, as shortage of primary health care workers may compromise the quality of patient care. Smith (2019, para.3) states that "each primary care physician is estimated to spend more than 17 hours each day in the provision of acute, chronic, and preventative health care." Moreover, this is not a problem that is restricted merely to the United States, but is rather a challenge that has become prevalent worldwide as similar trends and developments have been observed across Europe, Asia, and other regions as well (Wu and Lam, 2016; Kuhlmann et al., 2015; Committee on Pediatric Workforce, 2015).

What is more, in recent years, the shortage of dentists has become even more prevalent internationally, and various outlets are now calling the situation a "crisis" (Minjarez, 2017; Beek and Davidson, 2016). This is likely to have even more detrimental consequences in geographic areas that are already underserved and where the incentive for a market-driven solution to the dentist shortage is low (Voinea-Griffin and Solomon, 2016). This is of particular concern, as the role of dentistry has often been overlooked in the overall discourse on health care

(Giddon et al., 2013). This is in spite of the fact that dentistry is one of the world's oldest medical professions, harkening as far back as 7000 BC (American Dental Education Association, 2019). Much like primary care, it is predicted that in the United States, increases in dentist supply will not meet the increases in demand for dentists. This will, in turn, lead to an exacerbation of the existing shortage, and it is anticipated that the entire United States will experience a dentist shortage by 2025 (US Department of Health and Human Services, Health Resources and Services Administration and National Center for Health Workforce Analysis, 2015).

Just like with primary care, this dentistry situation is reflected in several other countries worldwide as well. For instance, in the Netherlands, the workforce of practicing dentists is rapidly decreasing due to aging. In 2017, there were approximately 10,000 dentists working in the Netherlands. From this selection, only 29 percent were younger than 40 years of age (Schreijer, 2018). Beyond that, 56 percent of those dentists under 40 were female (Schreijer, 2018; Van der Zande et al., 2015). In the Netherlands, it is not uncommon for women to combine their careers with their families by working part-time (Pieters, 2018; Kalmijn and Luijkx, 2006). This means that the effective amount of full-time employed dentists is not enough to saturate the market consisting of an ageing workforce. Moreover, the annual number of new dentists graduating and entering the profession (roughly less than 240) is not in parity with the number retiring each year (approximately 300) (DutchNews, 2019). On this account, it should be noted that approximately 78 percent of all Dutch people visit the dentist at least once a year, and out of this group, each person will visit their clinic about 2.7 times per year on average (Versteeg, 2016).

In the United Kingdom, the British Dental Association (BDA) figures published in 2018 indicated that 68 percent of National Health Service (NHS) practices in England struggled to fill vacant posts, which was an 18 percent rise on the 2016 figure (British Dental Association, 2018). In past few years, it has been reported the recruitment crisis at the United Kingdom's largest provider, Mydentist (with 10 million patients on its books), has become so dire it has left thousands of Britons unable to see NHS dentists (British Dental Association, 2019). This resulted in patients having to wait several months to see a dentist (Ford, 2019; Gupta, 2017). While there are a few countries in Europe where the number of recruited dentists has increased in the past few years (such as Lithuania), several other countries have shown a downward trend (including Greece, Denmark, France, etc.) (Fedcar, 2017).

A 2017 study showed that a lingering consequence following the 2008 European financial crisis is that fewer people with low incomes tend to visit the dentist today (Elstad, 2017). The same study also concluded that Ireland, Spain, and Switzerland were among the countries with the worst insurance coverage of health services, while several Eastern European countries, such as Slovakia, Slovenia, and the Czech Republic, had the best dental coverage. The reason for this is that these countries have to a large extent preserved much of the state-run health system that was present during the Cold War era (Elstad, 2017; Balci, 2017). These countries do not face the same projected population growth as many

of the Western European countries, and introducing a similar type of state-run health system in the rest of Europe will likely be impossible for political and market reasons. Moreover, many of the state-run subsidies only cover routine visits and check-ups. In Slovakia, for instance, dental care is chiefly private, with dentists being paid on a fee-for-service basis, and specialized dental treatment (e.g., crowns and bridges) will cost the patients extra. To exemplify, depending on the material used, a cavity treatment can in itself cost up to €80 (EURACTIV Slovakia, 2012). The situation in the Czech Republic follows a similar pattern, with dental insurance largely covering basic dental care. This entails limited numbers of the most usual treatment measures, with those wishing to pay out of their own pocket being more likely to gain access to more advanced dental equipment (Manski et al., 2015). Moreover, in some European countries, such as Germany, the dental health service is to a large extent included in the normal health service insurance schemes. In other countries like in Norway, most adults would need to fund their regular dental health services entirely out of their own pocket, even though private insurances may provide a solution to some people who have a subscription (Balci, 2017).

One may thus conclude that the dental welfare deficit is a twofold problem. On the one hand, there is the matter of a shrinking dentistry workforce. On the other hand, there is a matter of unaffordable dental care for large parts of the population in many parts of the world. Thus, the situation would seemingly call for a new and radical approach to address these problems. To this end, arguments have been raised in regard to digital dentistry and its potential to stem the tide. Specifically, the contention is that the application of digital dentistry could take some of the workload off dentists for less complex procedures, as these could then be handled by midlevel providers, which in turn results in more accessible dental care at lower cost. Hence, by discussing extant literature and best-practice developments in the area, this chapter aims to investigate the potential for digital dentistry to address the dental welfare deficit problem in its aspiration of providing more effective and more affordable dental care in the future.

2 The origins of digital dentistry: computer-aided design/computer-aided manufacturing

In the words of Schleyer (1999, p. 1713), the aim of digital dentistry is to develop "a cadre of experts in dental informatics, relying on sound research principles, effectively disseminating best practices and developing strategic objectives for the implementation of technology." At bedrock, digital dentistry is in itself not a new concept per se, as computer-aided design and computer-aided manufacturing (CAD/CAM) had already been invented in 1973 and implemented in practice more regularly during the 1980s (Ritter, Boushell and Walter, 2019; Lin, 2018). While there is no question that dental CAD/CAM revolutionized dentistry, it was in its early stages considered to be somewhat of a unwieldy novelty, as it required a disproportionate amount of time to produce a viable product due to slow speeds and a cumbersome interface (Tang, Medioni and Duret, 1998).

The purpose behind the development of the CAD/CAM was that, before its inception, it was difficult for dentists to construct crown and bridge structures, as this requires capacity to freely design a three-dimensional crown form, that is, full occlusal proximal, labial (buccal), and lingual surfaces, freely (Ueda and Yamaguchi, 2017). In time, use of CAD/CAM became the quintessential way to support the processing method and workflow. Dental CAD/CAM systems have continued to advance rapidly, and nowadays 3D model scanners and dental CAD/CAM systems are used worldwide (Ueda and Yamaguchi, 2017). Today there are a multitude of different chairside and laboratory-based CAD/CAM systems, such as Procera (Nobel Biocare), Lava (3M ESPE), Cercon (DENTSPLY Ceram-co), CEREC (Sirona), and E4D (D4D Technologies), just to name a few examples. These systems are used to design and manufacture metal, alumina, and zirconia frameworks, as well as all-ceramic and composite full-contour crowns, inlays, and veneers (McLaren, Culp and White, 2008).

3 The next steps in digital dentistry

Nowadays, digital dentistry has evolved far beyond the mere use of CAD/CAM, and several other digital technologies are currently used by dentists all over the world. For instance, intraoral cameras (IOCs) are cameras used by dentists to show a patient the interior of their mouth, rather than using a mirror. They were first developed in the late 1980s as oversized mobile units, and have through the decades shrunk to pocket-sized lightweight wands (Darby and Walsh, 2015). An advantage of using these is that they have the ability to magnify teeth 40 to 60 times their original size, making it possible for the dentist to identify defects within the oral cavity.

In more recent years, however, there have been particular advancements in the development of 3D printing and virtual reality (VR) and augmented (AR) reality. Three-dimensional printing, for instance, has been hailed as a disruptive technology that will change the very essence of manufacturing. Three-dimensional printing has a particular resonance with dentistry, with its use including everything from "the production of drill guides for dental implants, the production of physical models for prosthodontics, orthodontics and surgery, the manufacture of dental, craniomaxillofacial and orthopedic implants, and the fabrication of copings and frameworks for implant and dental restorations" (Dawood et al., 2015, p. 521). In other words, 3D printing may be used to for a variety of different procedures, such as printing physical models of digital images taken with intra-oral scans, making appliances, temporaries, surgical guides, and so on (Oberoi et al., 2018). Essentially, 3D printing in dentistry can be used for anything from repairing broken teeth to making dental flossing easier.

3.1 Three-dimensional printing

It should be stressed that in dentistry, there is a need for 3D printers to be particularly accurate. This means that the most common technologies used are

stereolithography (SLA) and digital light processing (DLP) (Hay, 2019). The advantage of 3D printing is that it may be used in the dentist's office as well as in labs. Hence, it brings a new level of speed and ease to old procedures. Also, the advantage of using a 3D model in dentistry as opposed to a plaster model is that a 3D model is more stable, durable, and precise (Borgwardt, 2017). While 3D printing is still a comparatively new phenomenon in dentistry, it is still in a growing and developing stage, while also being a multimillion-dollar industry (McCue, 2017; Haria, 2017). Hence, there should be a future incentive for the market to continue investing in dental 3D printing.

While there are seemingly infinite ways for dentists to use dental 3D printers, there is still a need for a "community of practice" and common standards that is thus far largely bereft from dentistry, although it can be expected that such will emerge in the coming decade. Also, although 3D printing carries many advantages, there are some additional disadvantages. Specifically, 3D printing carries a considerable cost of running, in addition to the cost of materials, maintenance, and skilled operators. This technology also places new demands on postprocessing as well as adherence to strict health and safety protocols. There may also be some additional environmental concerns, as 3D printing tends to consume exorbitant amounts of electricity and may lead to harmful emissions (Pearson, 2018).

3.2 Virtual reality and augmented reality

An even newer phenomenon is the occurrence of VR and AR in dentistry. Both technologies are useful for educational purposes, that is, training new dentists. In this way, both of these technologies are likely to radically alter the future clinical training of dentistry and encourage the use of reflective forms of assessment. This may include having dentistry students undertaking greater degrees of self-assessment procedures in order to identify individual learning needs and self-directed learning. In that way, VR and AR may serve to lower the costs of the educational process, thereby enabling the funding of more dental students. These technologies may also to increase educational quality by providing new tool to dental schools so that future dentistry graduates may perfect their skillsets and aptitudes further (Roy, Bakr and George, 2017; Dutã et al., 2011; Huang et al., 2018).

Notwithstanding, VR and AR are not exclusive only to dental students, as the technologies may also continue to have practical usefulness during patient interaction. To the point, the VR technology inherently requires a large headpiece that covers the eyes, thus "inserting" users in a virtual world where they can interact with their new surroundings. In dentistry, the advantages can be seen primarily in the enhancement of the patient experience. For instance, VR can in some cases be used to help ease patient anxieties or even offer pain relief, as studies have shown that VR can lessen the perception of pain (Benham, Kang and Grampurohit, 2019; Wiederhold et al., 2014). VR thus allows for patients to become immersed in an interactive experience, thereby distracting them from the dental procedure.

AR, on the other hand, is distinguishable from VR in the sense that it provides not only virtual information, but also interacts with the environment that

surrounds the user. AR provides the user with a great degree of freedom, and unlike VR, it does not need to cover the user's eyes and does not necessitate any unwieldy, bulky pieces of equipment. While VR provides for a greater sense of immersion in a given, set scenario, AR allows users to practice procedures regardless of where they are. As such, AR in dentistry is chiefly concentrated within the surgery realm (Kwon, Park and Han, 2018; Huang et al., 2018). To this end, dentists can practice complex procedures with no risk to patients and with minimal costs, as no material (save for some electricity) is disposed of during the practice runs, making it a cost-efficient solution.

Just like with VR, AR can also be used to enhance the patient experience for certain procedures. For instance, with AR, rather than taking a cast of the patient's mouth, sending it off to a dental lab, and waiting for it to be processed and sent back, the dentist has the advantage of giving the patient an immediate visual representation of the completed proposed treatment (Jain, 2017). This may include orthodontics, crown and bridgework, implants, and so on. This saves both time and money for the patient as well as the dentist and the welfare system (if funded via that route) while also proving the patient with a greater sense of what to expect.

4 Concluding discussion

This chapter set out to discuss if and how digital dentistry could offer a solution to the impending dental welfare deficit problem. The problem is in part caused by the sheer number of diminishing active dentists in the workforce, and in part by the unaffordable dental care that is keeping large parts of the population from seeking dental care. In answering these questions, this chapter has investigated some of the most prominent new technologies found in digital dentistry, with an emphasis on 3D printing as well as VR and AR.

The future applications of said technologies are for all intents and purposes limitless.

Three-dimensional printing could provide for the possibility of instantaneous manufacturing of needed products, effectively eliminating, or at least heavily reducing, the need for processing casts and imprints and so on at specialist labs. In that way, the automation process also reduces the likelihood of human errors, ensuring a greater degree of predictability in the final results. It may also allow for greater precision and higher quality of dental appliances manufactured. Assuming that the 3D printer is operated by someone with the right competency, it should be less labor intensive than other techniques. This means that manufacturing models and appliances would become a fully automated, unsupervised process. This, in turn, will save the dentist much valuable time.

Moreover, if a dentist were to be able to take instantaneous virtual scans of patient's mouth, or even if patients would have the technological means to take scans of their own mouths, after which custom-built pieces could be manufactured, dentistry as we know it would be a thing of the past. Seeking initial dental care would in many cases be no more cumbersome than standing in line at the grocery store. Keeping the length of each appointment as short as possible, while

keeping the number of required repeat visits to a minimum, is in the best interest for both patients as well as dentists. If digital dentistry can help shorten lead times, much time may be saved, which may help lower fatigue rates among practitioners, or alternatively increase patient volume.

Other potential advantages brought forth by digital dentistry are the possibilities of having an overlay of information displaying a wider range of patient data and metrics for monitoring during dental procedures. Another possibility would be for dental students to digest information more rapidly with an AR-supported course that could provide helpful illustrations and/or interactive visuals along with the lecture.

If these technologies were utilized in a way that made it possible to make them work together, it would increase efficiency, lower costs, and enhance the patient experience profoundly. Nevertheless, while digital technology can present the physical means of addressing the dental welfare deficit problem, the problem will never get resolved unless there is also a political as well as a market incentive to do so. For instance, using digital dentistry to cut costs and save resources during dental education programs could provide schools with the means to accept more students each year. By reducing waste of time and resources in dentistry, dentists may find themselves in a less stressful environment while also being able to see more patients. By being able to craft the necessary material needed for dental procedures through 3D printing, it is easier to estimate costs and the amount of resources needed. This should in turn provide for more affordable dental care. Still, these areas are by and large to a large extent governed by regulation as well as by market incentives. Once the technology is perfected and in place, it is therefore important to raise awareness among policy-makers so that the technology will be utilized in an optimal fashion that benefits dentists, patients, and society at large.

References

American Dental Education Association, 2019. *History of dentistry*. [online] ADEA GoDental. Available at: <www.adea.org/GoDental/Health_Professions_Advisors/History_of_Dentistry.aspx> [Accessed 10 Sep. 2019].

Balci, S., 2017. *Low-income earners skip going to the dentist*. [online] ScienceNordic. Available at: <http://sciencenordic.com/low-income-earners-skip-going-dentist> [Accessed 10 Sep. 2019].

Beek, M. Van and Davidson, J., 2016. *Dental therapists: a proposal to expand access to dental care in Michigan*. [online] Texas Public Policy Foundation. Available at: <www.texaspolicy.com/dental-therapists-a-proposal-to-expand-access-to-dental-care-in-michigan> [Accessed 10 Sep. 2019].

Benham, S., Kang, M. and Grampurohit, N., 2019. Immersive virtual reality for the management of pain in community-dwelling older adults. *OTJR: Occupation, Participation and Health*, 39(2), pp. 90–6.

Borgwardt, E., 2017. *Great benefits of using 3D-printing and digital models in the dental industry*. [online] ELOS Medtech. Available at: <https://elosmedtech.com/great-benefits-of-using-3d-printing-and-digital-models-in-the-dental-industry> [Accessed 10 Sep. 2019].

British Dental Association, 2018. *NHS dentistry facing recruitment crisis*. [online] Press Release. Available at: <https://bda.org/news-centre/press-releases/nhs-dentistry-facing-recruitment-crisis> [Accessed 10 Sep. 2019].

British Dental Association, 2019. *75% of NHS dental practices now struggling to fill vacancies*. [online] Press Release. Available at: <https://bda.org/news-centre/press-releases/75-per-cent-of-nhs-dental-practices-now-struggling-to-fill-vacancies> [Accessed 10 Sep. 2019].

Committee on Pediatric Workforce, 2015. The use of telemedicine to address access and physician workforce shortages. *Pediatrics*, 136(1), pp. 202–9.

Darby, M.L. and Walsh, M., 2015. *Dental hygiene: theory and practice*. 4th ed. St. Louis, MO: Elsevier.

Dawood, A., Marti, B.M., Sauret-Jackson, V. and Darwood, A., 2015. 3D printing in dentistry. *British Dental Journal*, 219(11), pp. 521–9.

Dutã, M., Amariei, C.I., Bogdan, C.M., Popovici, D.M., Ionescu, N. and Nuca, C.I., 2011. An overview of virtual and augmented reality in dental education. *OHDM*, 10(1), pp. 42–9.

DutchNews, 2019. *More foreign dentists are filling the gap as dentist shortage grows*. [online] Available at: <www.dutchnews.nl/news/2019/03/more-foreign-dentists-are-filling-the-gap-as-dentist-shortage-grows> [Accessed 10 Sep. 2019].

Elstad, J.I., 2017. Dental care coverage and income-related inequalities in foregone dental care in Europe during the great recession. *Community Dentistry and Oral Epidemiology*, 45(4), pp. 296–302.

EURACTIV Slovakia, 2012. *Social situation in Slovakia still a painful issue*. [online] Available at: <www.euractiv.com/section/eu-priorities-2020/news/social-situation-in-slovakia-still-a-painful-issue> [Accessed 10 Sep. 2019].

Fedcar, 2017. *Updated figures on practising dentists in Europe: no general shortage*. [online] Available at: <http://fedcar.eu/en/news/europe/2017/02/updated-figures-on-practising-dentists-in-europe> [Accessed 10 Sep. 2019].

Fodeman, J. and Factor, P., 2015. Solutions to the primary care physician shortage. *The American Journal of Medicine*, 128(8), pp. 800–1.

Ford, J., 2019. *Thousands of new patients unable to get dentist appointment on NHS, according to survey*. [online] East Anglian Times. Available at: <www.eadt.co.uk/news/thousands-of-people-unable-to-get-an-nhs-dental-appointment-in-suffolk-survey-reveals-1-5876727> [Accessed 10 Sep. 2019].

Giddon, D.B., Swann, B., Donoff, R.B. and Hertzman-Miller, R., 2013. Dentists as oral physicians: the overlooked primary health care resource. *The Journal of Primary Prevention*, 34(4), pp. 279–91.

Gupta, R., 2017. Some new dentists unable to do NHS work, say British Dental Association. *BBC News*. [online] Available at: <www.bbc.com/news/health-38534758> [Accessed 10 Sep. 2019].

Haria, R., 2017. *How 3D printing has changed dentistry, a billion dollar opportunity*. [online] 3D Printing Industry. Available at: <https://3dprintingindustry.com/news/3d-printing-impact-on-dentistry-121284> [Accessed 10 Sep. 2019].

Hay, Z., 2019. *Dental 3D printing – all you need to know in 2019*. [online] All3DP. Available at: <https://all3dp.com/2/dental-3d-printing-all-you-need-to-know> [Accessed 10 Sep. 2019].

Huang, T-K., Yang, C-H., Hsieh, Y-H., Wang, J-C. and Hung, C-C., 2018. Augmented reality (AR) and virtual reality (VR) applied in dentistry. *The Kaohsiung Journal of Medical Sciences*, 34(4), pp. 243–8.

Ito, T., Hamid, R.A. and Ichikawa, T., 2016. Collaborative design and manufacturing of prosthodontics wire clasp. In: M. Borsato, N. Wognum, M. Peruzzini, J. Stjepandić and W.J.C. Verhagen, eds. *Transdisciplinary engineering: crossing boundaries: proceedings of the 23rd ISPE Inc. International Conference on Transdisciplinary Engineering*, 3–7 October. Amsterdam, Netherlands: IOS Press, pp. 421–8.

Jain, R., 2017. *Augmented reality dentistry will show you how your teeth look post-treatment*. [online] International Business Times. Available at: <www.ibtimes.com/augmented-reality-dentistry-will-show-you-how-your-teeth-look-post-treatment-2586615> [Accessed 10 Sep. 2019].

Kalmijn, M. and Luijkx, R., 2006. Changes in women's employment and occupational mobility in the Netherlands: 1955 to 2000. In: H-P. Blossfeld and H. Hofmeister, eds., *Globalization, uncertainty and women's careers: an international comparison*. Cheltenham, UK: Edward Elgar Publishing, pp. 84–114.

Kuhlmann, E., Groenewegen, P.P., Batenburg, R. and Larsen, C., 2015. Health human resources policy in Europe. In: E. Kuhlmann, R.H. Blank, I.L. Bourgeault and C. Wendt, eds. *The Palgrave international handbook of healthcare policy and governance*. London, UK: Palgrave Macmillan, pp. 289–307.

Kwon, H-B., Park, Y-S. and Han, J-S., 2018. Augmented reality in dentistry: a current perspective. *Acta Odontologica Scandinavica*, 76(7), pp. 497–503.

Lin, Y-M., 2018. Digitalisation in dentistry: development and practices. In: Y-C. Kim and P-C. Chen, eds. *The digitization of business in china: exploring the transformation from manufacturing to a digital service hub*. Cham, Switzerland: Palgrave Macmillan, pp. 199–217.

Manski, R., Moeller, J., Chen, H., Widström, E., Lee, J. and Listl, S., 2015. Disparity in dental coverage among older adult populations: a comparative analysis across selected European countries and the USA. *International Dental Journal*, 65(2), pp. 77–88.

McCue, T.J., 2017. *3D printing moves align technology toward $1.3 billion in sales*. [online] Forbes. Available at: <www.forbes.com/sites/tjmccue/2017/09/14/3d-printing-moves-align-technology-toward-1-3-billion-in-sales> [Accessed 10 Sep. 2019].

McLaren, E., Culp, L. and White, S., 2008. The evolution of digital dentistry and the digital dental team. *Dentistry Today*. [online]. Available at: <www.dentistrytoday.com/restorative-134/1789–sp-1323704604> [Accessed 10 Sep. 2019].

Minjarez, J., 2017. *America's dental crisis is happenin: here is the solution*. [online] RealClear: Health. Available at: <www.realclearhealth.com/articles/2017/08/24/americas_dental_crisis_is_happening_here_is_the_solution_110712.html> [Accessed 10 Sep. 2019].

Oberoi, G., Nitsch, S., Edelmayer, M., Janjić, K., Müller, A.S. and Agis, H., 2018. 3D printing – encompassing the facets of dentistry. *Frontiers in Bioengineering and Biotechnology*, 6, pp. 172, 1–13.

Pearson, A., 2018. *10 Disadvantages of 3D printing technology*. [online] 3DInsider. Available at: <https://3dinsider.com/3d-printing-disadvantages> [Accessed 10 Sep. 2019].

Petterson, S.M., Liaw, W.R., Phillips, R.L., Rabin, D.L., Meyers, D.S. and Bazemore, A.W., 2012. Projecting US primary care physician workforce needs: 2010–2025. *Annals of Family Medicine*, 10(6), pp. 503–9.

Pieters, J., 2018. Young Dutch women work least hours in Europe. *NL Times*. [online] Available at: <https://nltimes.nl/2018/01/22/young-dutch-women-work-least-hours-europe> [Accessed 10 Sep. 2019].

Ritter, A.V., Boushell, L.W. and Walter, R., 2019. *Sturdevant's art & science of operative dentistry*. 7th ed. St. Louis, MO: Elsevier.

Roy, E., Bakr, M.M. and George, R., 2017. The need for virtual reality simulators in dental education: a review. *The Saudi Dental Journal*, 29(2), pp. 41–7.

Schleyer, T.K.L., 1999. Digital dentistry in the computer age. *The Journal of the American Dental Association*, 130(12), pp. 1713–20.

Schreijer, S., 2018. *There is a shortage of dentists in Holland – and it's growing*. [online] BGB Dentistry. Available at: <www.dentistinholland.com/there-is-a-shortage-of-dentists-in-holland-and-its-growing> [Accessed 10 Sep. 2019].

Smith, Y., 2019. *Strategies to improve shortage of primary health care*. [online] News medical: life sciences. Available at: <www.news-medical.net/health/Strategies-to-Improve-Shortage-of-Primary-Health-Care.aspx> [Accessed 10 Sep. 2019].

Tang, C-K., Medioni, G. and Duret, F., 1998. Automatic, accurate surface model interference fo dental CAD/CAM. In: W.M. Wells, A. Colchester and S. Delp, eds. *Medical image computing and computer-assisted intervention – MICCAI'98: first international conference*, Cambridge, MA, 11–13 October, Proceedings. Heidelberg, Germany: Springer, pp. 732–42.

Ueda, Y. and Yamaguchi, T., 2017. History of and current situation regarding dental CAD/CAM systems and future perspectives. *Hokkaido Journal of Dental Science*, 38(Special issue), pp. 104–10.

US Department of Health and Human Services, Health Resources and Services Administration and National Center for Health Workforce Analysis, 2015. *National and state-level projections of dentists and dental hygienists in the U.S., 2012–2025*. [online] Available at: <https://bhw.hrsa.gov/sites/default/files/bhw/nchwa/projections/nationalstatelevelprojectionsdentists.pdf> [Accessed 10 Sep. 2019].

Versteeg, A., 2016. *Dutch dentistry: trends & developments*. [online] BGB Dentistry. Available at: <http://web.archive.org/web/20170512204041/http://www.dentistinholland.com/dutch-dentistry-trends> [Accessed 10 Sep. 2019].

Voinea-Griffin, A. and Solomon, E.S., 2016. Dentist shortage: an analysis of dentists, practices, and populations in the underserved areas. *Journal of Public Health Dentistry*, 76(4), pp. 314–19.

Wiederhold, B.K., Gao, K., Sulea, C. and Wiederhold, M.D., 2014. Virtual reality as a distraction technique in chronic pain patients. *Cyberpsychology, Behavior, and Social Networking*, 17(6), pp. 346–52.

Wu, D. and Lam, T.P., 2016. Underuse of primary care in China: the scale, causes, and solutions. *Journal of the American Board of Family Medicine: JABFM*, 29(2), pp. 240–7.

Van der Zande, M.M., Gorter, R.C., Aartman, I.H.A. and Wismeijer, D., 2015. Adoption and use of digital technologies among general dental practitioners in the Netherlands. *PLOS ONE*, 10(3), pp. e0120725, 1–13.