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Paulo G. Coelho, DDS, PhD
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The Wrong Questions

Kerry K. Carney, DDS, CDE

If they can get you asking the wrong questions, they don’t have to worry about the answers. — Thomas Pynchon (1973)

That quote was at the bottom of an email I received the other day. Usually, I do not even read the bon mots that, like a family motto, some folks feel compelled to share in their messages. However, this one made me stop and think.

Everywhere I look, important issues are being obscured by misdirection. In politics, promotions of logical fallacies are part of the standard playbook. But that tactic is becoming more and more evident in the advertising and press releases about e-cigarettes.

Editors receive frequent “pitches” from publicists. This summer, a public relations firm contacted me with the following email subject line:

Global conf. aims to eliminate death from smoking through safer nicotine delivery

It was stunning. In a dozen words, the public health issue of cigarette smoking and its causal relationship with sickness and death was confounded with the idea that the whole problem is that darn cigarette. The spin is: That smoldering cancer stick is the issue. If we all get behind an alternative nicotine delivery system that circumvents the cigarette, then “Bob’s your uncle” — everything will be fine, there is no public health problem.

The pitch went on to say: “Last week’s Global Forum on Nicotine in Warsaw, Poland, brought together 600 delegates from 70 countries — experts and advocates in tobacco and nicotine science and policy — to discuss tobacco harm reduction on the theme ‘It’s time to talk about nicotine.’”

This forum does not sound too bad. It sounds very “sciency,” right? But are they asking the right question? Why is it time to talk about tobacco harm reduction and not nicotine addiction? Maybe it was a typo.

The next line in the email stated in bold type: “For the first time in 120 years, we could eliminate the death and disease caused by the cigarette rolling machine.” The implication is that darn machine is the public health problem. If we just promoted alternative nicotine delivery systems, we could thwart the dangerous “cigarette rolling machine.” One might wonder, if that machine is as dangerous as a forum presenter claimed, then in accordance with the tobacco industry’s “tobacco harm reduction initiative,” it would pull the plug on those bad machines. Why would tobacco companies continue to promote cigarettes and smoking on a global scale if they are dedicated to tobacco harm reduction? (Or maybe I have it all wrong. Maybe the cigarette rolling machine is so dangerous because it actually crushes consumers. No, that can’t be right). I guess the question being asked is: How can we get rid of dangerous cigarettes and still enjoy nicotine? But is that really the question we should be asking?

Then something dangerous happened. I was alone with my computer and I was bored. So I started googling the Global Forum on Nicotine (GFN). What I found out about the convention and accompanying tech show (read: vendors’ marketplace) allowed me to understand the misdirection and newspeak that was being pitched.

The event promotes itself as a forum for global public health debate. According to the website, the GFN is “unique among conferences on nicotine and smoking, we ensure that consumer and consumer advocacy organisations participate as well as manufacturers.” Their program honors Michael Russell, who may have been the first to articulate the “tobacco harm reduction” ideology. GFN reiterates his tenet that, “Smoking tobacco is the most harmful way of using nicotine. It is the tars and gases in cigarette smoke that are harmful to health. Many people find it hard to stop smoking because they find it hard to go without nicotine. Making available lower-risk products helps people to switch from smoking and avoid the associated risks. This is known as ‘tobacco harm reduction.’”

The whole idea of “harm reduction” works to the advantage of the tobacco industry in that it “disentangles the notion that (substance) use equals harm and instead identifies the negative consequences of (substance) use as the target for intervention rather than (substance) use itself.” This is how tobacco companies can support alternative nicotine delivery systems while they “simultaneously work to promote cigarette smoking and undermine tobacco control globally.”

A little foray into the tobacco harm reduction discussion on the web was like a little stroll with Alice through Wonderland. There were a lot of “discussions” and

“Nicotine, despite what the cigarette companies say, is not like caffeine. It’s a neurotoxin; it changes your brain and your nervous system...”
many questions that, if followed, could lead the reader down one rabbit hole after another. To paraphrase Thomas Pynchon: If the tobacco industry and the makers of alternative nicotine delivery systems can get you asking the wrong questions, they don’t have to worry about the answers.

Maybe we should be thinking a little more about the questions that we want answered.

One right question might be, what are the ramifications of nicotine addiction?

According to Dr. Stanton Glanz, a University of California, San Francisco, professor and nationally recognized expert on the tobacco industry, “Nicotine, despite what the cigarette companies say, is not like caffeine. It’s a neurotoxin; it changes your brain and your nervous system … And it’s very well established that the younger kids are when they start using nicotine, the more heavily addicted they get, the longer they use and the harder time they have quitting.”

Or maybe a right question is, what is the role of alternative nicotine delivery systems in cardiovascular disease?

Or maybe we should be asking, what is the connection between alternative nicotine delivery systems and pulmonary function or noncancer lung disease risk?

There exists evidence “that bystanders absorb nicotine when people around them use e-cigarettes at levels comparable with exposure to conventional cigarette secondhand smoke.” So maybe we should be asking about alternative nicotine delivery systems’ effects on our clean air and its secondary effect on us.

When Alice confronts the hookah-smoking caterpillar in Wonderland, she had been reduced to 3 inches in height. She tries to ask him how to grow back to her normal height again. Their conversation is a study in wrong questions and misdirected answers. Alice’s confusion may have been the result of the secondary smoke of the caterpillar’s hookah. However, in the end, as the caterpillar gut-slides away, he indicates he was sitting on the answer to the right question, the important question, all along: One side of his mushroom will make her larger and the other will make her small.

To get meaningful answers, we must make sure we are asking the right questions.

REFERENCES
1. Seventh Global Forum on Nicotine. gfn.net.co/faq.

CORRECTIONS
In the August 2019 issue’s article by Newton et al., the MCDAS as depicted in the figure on page 524 was incorrectly referenced to Wong et al. The correct citation is Howard KE, Freeman R. Reliability and validity of a faces version of the Modified Child Dental Anxiety Scale. Int J Paediatr Dent 2007; 17:281–288. The abstract on page 579 of the September 2019 issue had an error. The X-ray exposure recommendations were last revised in 2012 not 2018.
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Discovery Could Allow for Root Regeneration

Researchers are increasingly looking to understand epigenetics, the study of changes in organisms caused by modification of gene expression rather than alteration of the genetic code itself, to learn how the body changes over time. This scientific endeavor extends to teeth as well.

Yang Chai, DDS, PhD, associate dean of research at the Herman Ostrow School of Dentistry of USC, and colleagues discovered that epigenetic regulation can control tooth root patterning and development. Their study was published in the research magazine *eLife* in July.

“This is an aspect that doesn't involve change in the DNA sequence, but it's basically through the control where you make the genes available or unavailable for transcription, which can determine the pattern,” Dr. Chai said.

A protein called EZH2 helps the bones of the face to develop, but it was not known how the protein affects tooth root development, according to the study. So the researchers examined what happens when EZH2 is not present in the molar teeth of developing mice. They found that EZH2 and another protein called ARID1A must be in balance to establish the tooth root pattern and the proper integration of roots with the jaw bones.

“I feel excited about this because, through human evolution, there have been changes in our diet and environment that can influence our epigenome — the ways our genes are regulated — and you can clearly see a difference between the root formation of our dentition versus Neanderthals,” said Dr. Chai. He explained that Neanderthal molars have longer root trunks than the ones seen in anatomically modern humans and show late splitting of the roots. This could be due to the effect of diet and exercise on the proteins that turn the genes on and off.

The balance of regulators also has a hand in disease and wellness. In different types of cancer, research has shown that the balance of two opposing epigenetic regulators is important. Knocking out one regulator can create cancer, Dr. Chai said, but modulating its opposing regulator can stop the cancer.

“These epigenetic regulators, which are not changing the DNA sequences, are important in themselves, but the level of their activity is also important,” he said. “Basically, you can’t have too much or too little — if the balance is off track, then you get developmental problems or disease.”

The ultimate goal of Dr. Chai’s research on the regulation of tooth development is to regrow teeth. But generating an entire tooth is challenging because of the amount of time it takes for nature to build a tooth from development to eruption. So he aims to find ways to regenerate a molar root ... and put a crown on top.

Learn more about this study in *eLife* (2019); doi.org/10.7554/eLife.46426.
Perio Treatment Plus aPDT Lowers Glucose Levels

Researchers from China found that patients with diabetes and chronic periodontitis had improved glycemic levels when their periodontal disease was treated with scaling and root planing (SRP) plus antimicrobial photodynamic therapy (aPDT) and the antibiotic doxycycline, according to a meta-analysis published in *BMC Oral Health*.

The researchers wanted to determine which periodontal treatment best controlled glycemic levels in patients diagnosed with Type 2 diabetes and chronic periodontitis, so they searched medical and scientific databases for randomized controlled trials through May 2018 and included 14 trials in their analysis.

The trials involved 629 patients with both periodontitis and Type 2 diabetes who had severe gum disease treated with scaling and root planing. The patients had no other systemic diseases. The patients had Type 2 diabetes for between four and almost 12 years, and their treatments primarily included diet and insulin supplementation or oral antidiabetic medications. The baseline of hemoglobin A1c levels in the patients varied between 6.2 to 10.4.

The use of SRP with photodynamic therapy and doxycycline improved levels of hemoglobin A1c, an indicator of how well diabetes is being controlled, better than SRP alone or SRP with antibiotics, according to the research. The treatment combination was most effective for patients who didn’t smoke or had severe Type 2 diabetes complications.

While longer-term, well-executed, multicenter trials are needed to corroborate the results, the findings of the meta-analysis seemed to support that SRP with photodynamic therapy plus the use of doxycycline had the best efficacy in lowering glycemic levels.

Read more of this study in *BMC Oral Health* (2019); doi.org/10.1186/s12903-019-0829-y.

Antibiofilm Mechanism in Nanoparticles Breaks Apart Dental Plaque

In a study published recently in *Nature Communications*, researchers from the University of Pennsylvania used FDA-approved nanoparticles to effectively disrupt biofilms and prevent tooth decay in both an experimental human-plaque-like biofilm and in an animal model that mimics early childhood caries. The nanoparticles break apart dental plaque through a unique pH-activated antibiofilm mechanism.

“It displays an intriguing enzyme-like property whereby the catalytic activity is dramatically enhanced at acidic pH but is ‘switched off’ at neutral pH conditions,” said Hyun (Michel) Koo, DDS, MS, PhD, professor in the UP School of Dental Medicine. “The nanoparticles act as a peroxidase, activating hydrogen peroxide, a commonly used antiseptic, to generate free radicals that potently dismantle and kill biofilms in pathological acidic conditions but not at physiological pH, thus providing a targeted effect.”

Because the caries-causing plaque is highly acidic, the new therapy is able to precisely target areas of the teeth harboring pathogenic biofilms without harming the surrounding oral tissues or microbiota.

The particular iron-containing nanoparticle used in the experiments, ferumoxytol, is already FDA-approved to treat iron deficiency, which is a promising indication that a topical application of the same nanoparticle, used at a several hundredfold lower concentration, would also be safe for human use, according to the study.

Though some scientists have questioned whether coatings used on ferumoxytol and other nanoparticles used for medical applications would render them catalytically inert, Dr. Koo and colleagues demonstrated that they maintained peroxidase-like activity, activating hydrogen peroxide.

“We used plaque samples from caries-active subjects to reconstruct these highly pathogenic biofilms on real human tooth enamel,” said Dr. Koo. “This simulation showed that our treatment not only disrupts the biofilm but also prevents mineral destruction of the tooth’s surface. That offered very strong evidence that this could work in vivo.”

Further studies in a rodent model that closely mirrored the stages of caries development in humans showed that twice-a-day rinses of ferumoxytol and hydrogen peroxide greatly reduced the severity of caries on all of the surfaces of the teeth and also completely blocked the formation of cavities in the enamel.

Read more about this study in *Nature Communications* (2019); doi.org/10.1038/s41467-018-05342-x.
Study Finds Oral Health Care Gaps Among Older Minorities

Regular visits with the dentist can be a challenge for older Americans and, as a recent study highlights, it can be even more difficult for minorities and immigrants. Researchers at NYU Rory Meyers College of Nursing and the University of Hawai‘i at Mānoa led the study, which was published recently in Research on Aging.

Researchers found that visits to the dentist drop significantly after adults turn 80 due to barriers such as a lack of access to quality dental care and dental insurance coverage. These roadblocks to dental care increase for racial and ethnic minorities and immigrants, who may experience racial discrimination and language barriers in health care settings, according to the study.

“Unlikely previous studies that only looked at recent trends of dental care among adults in the U.S., this study focused on middle-aged and older adults across an extended period of time. Researchers studied how often U.S. adults, 51 years and older, saw the dentist as they aged. Seventy percent of adults had visited a dentist in the past two years, but this rate decreased significantly beginning around age 80. While the frequency in visits decreased with age, researchers found the rates of decline for white adults were slower than black and Hispanic adults. “Our study went beyond prior research by confirming that racial and ethnic disparities were substantial and persistent as people became older, regardless of their birthplace and while adjusting for a wide range of factors,” said Bei Wu, PhD, dean’s professor in global health at NYU Rory Meyers College of Nursing and co-director of the NYU Aging Incubator as well as the study’s senior author.

Additionally, the study showed that adults born in the U.S. of all races and ethnicities were more likely to see a dentist than immigrants. Researchers noted that the gap in care between adults born in the U.S. and immigrants shrank as people aged, suggesting that age and acculturation may play a role in decreasing oral health disparities over time.

Learn more about this study in Research on Aging (2019); doi.org/10.1177/0164027519860268.

Stem-Cell Mechanism Could Offer New Solution to Tooth Repair

Stem cells hold the key for tissue engineering, as they develop into specialized cell types throughout the body, including in teeth. Along those lines, an international team of researchers, including scientists from the Biotechnology Center of the TU Dresden (BIOTEC), has found a new mechanism that could offer a potential new solution to tooth repair.

The study was published in the journal Nature Communications in August. The research team, led by Bing Hu, DDS, MD, PhD, of the Peninsula Dental School of the University of Plymouth, U.K., discovered a new population of mesenchymal stromal cells in a continuously growing mouse incisor model and have shown that these cells contribute to the formation of dentin. Importantly, the work showed that when these stem cells are activated, they send signals back to the mother cells of the tissue to control the number of cells produced through a molecular gene called Dlk1.

This study is the first to show that Dlk1 is vital for this process to work. In the same study, the researchers also demonstrated that Dlk1 can enhance stem cell activation and tissue regeneration in a wound-healing model. This mechanism could provide an innovative solution for tooth repair, addressing problems such as tooth decay, crumbling and trauma treatment. Further research is needed to validate the results for clinical applications to determine the appropriate duration and dose of treatment, according to the study.

Learn more about this study in Nature Communications (2019); doi.org/10.1038/s41467-019-11611-0.

A group of mesenchymal (green) stem cells migrating in a tooth to further regenerate tissues. (Credit: Media and Communications/University of Plymouth)
Interprofessional Education Improves Dental Health

Participating in interprofessional education (IPE) programs can help pediatric nurse practitioner students change oral health behaviors and prevent dental problems in patients, according to a new study published recently in BMC Oral Health.

Because few studies exist that evaluate IPEs in the oral health field, researchers from the Tufts University School of Dental Medicine in Boston conducted a pilot study to measure the impact these programs can have on oral health education and to assess their potential to assist nurse practitioners in improving pediatric oral health outcomes. The study included 16 first-year pediatric nurse practitioners from Northeastern University in Boston with a median age of 33. Most of the participants were women.

During the spring term of 2016, these students participated in an IPE, an oral health education seminar and a practical session. Following the program, student assessments showed that participants improved their overall health knowledge, with 100% of participants answering questions correctly about children’s first dental visits, bacteria causing tooth decay, age of referral and population group risk.

Participants also showed significant improvement, during and after the program, in their awareness of oral habits, examination of teeth, fluoride intake, dental counsel and baby bottle use. This was accompanied by improved confidence in the students’ abilities to identify teeth with cavities, plaque and enamel demineralization. Their ability to apply fluoride varnish also improved, according to the study.

“IPE may provide nurse practitioners and other nondental health care providers the adequate motivation, confidence and attitude regarding oral health issues,” said Azita Khanbodaghi, DMD, of the department of pediatric dentistry at the Tufts University School of Dental Medicine, who led the study. “The program is raising the importance of oral health components in nursing programs and ... nondental professionals, and in a referral system between pediatric nurse practitioners with pediatric/general dentists.”

Supporters of these IPE programs, which include the World Health Organization, the Institute of Medicine and the American Public Health Association, believe they help practitioners communicate better, improve quality of care, reduce patients’ costs and hospital lengths of stay and cut down on medical mistakes.

Read more about this study in BMC Oral Health (2019); doi.org/10.1186/s12903-019-0861-y.

Poor Oral Health in Childhood Associated With Heart Disease, Stroke

A study published in the JAMA Network Open in August found that people with oral infections in childhood were more likely to be at risk for heart disease and stroke later in life.

Researchers from the University of Helsinki and Helsinki University Hospital in Finland reviewed oral exams of 755 people who participated in the ongoing Cardiovascular Risk in Young Finns Study; the exams took place when the participants were an average age of 8 years old and then again 27 years later.

The research team found that the children with all four signs of oral infections (bleeding, cavities, fillings or pockets around the teeth) were 95% more likely to develop thickening of the artery walls than those with none. Even the children who only had one sign of oral infection were 87% more likely to develop artery damage, according to the study.

The risk of subclinical atherosclerosis associated with oral infections was especially substantial in boys, although only the number of sites with increased periodontal probing depth and the brushing frequencies differed by sex. Male participants with all four signs of oral infections in childhood had a 125% increased risk for high intima-media thickness values 27 years later.

An association between childhood oral infections with cardiovascular disease risk factors, particularly high blood pressure and BMI, was also evident.

This study suggests that oral infections in childhood are associated with the subclinical carotid atherosclerosis in adulthood, according to the authors.

Read more of this study in JAMA Network Open (2019); doi:10.1001/jamanetworkopen.2019.2523.
Excessive Computer Use Related to Teens’ Poor Oral Health

Too much computer time could put teenagers at risk for poor oral health, according to a new study published in the U.S. National Library of Medicine National Institutes of Health. Researchers examined more than 1,500 18-year-olds and found that those who spend more time on computers are significantly more likely to neglect their oral health.

“There is growing evidence to suggest that computer use is linked with a number of health problems for teenagers. Much of the attention in the past has focused on its relationships with obesity, smoking, drinking and changes in behavior,” said Nigel Carter, BDS, OBE, chief executive of the Oral Health Foundation in the U.K.

Teens who spent longer on a computer were less likely to brush their teeth, floss and visit the dentist, according to researchers. Their results showed that boys are particularly at risk, as twice-daily brushing dropped below 50% for those with excessive computer use.

Researchers also discovered a link between excessive computer use and school absences with up to 25% of teens more likely to suffer from bleeding gums and almost twice as likely to miss school because of dental pain.

Further findings revealed an uptick in sugar consumption among teens who spent more time on a computer. The amount and frequency of soda and juices with added sugar and snacking all increased for those with more than three hours of computer time a day.

“There is an urgent need for more education — on both the consequences of excessive computer use and the benefits of maintaining good oral hygiene. These need to be communicated to children and families before it begins to negatively affect their health and well-being,” said Dr. Carter.

Read more of this study in the U.S. National Library of Medicine National Institutes of Health (2019); dx.doi.org/10.1002%2Fcre2.183.

Study Finds Long-Term Periodontal Therapy Promotes Healthy Teeth and Gums

A recent study conducted by researchers in Switzerland found that decades-long periodontal treatment can help prevent tooth loss and tissue damage, in addition to helping patients maintain healthy gums. The study was published in the Journal of Clinical Periodontology in July.

“The present study shows long-term success of periodontal therapy over many years can be achieved in patients attending dental care in a general private practice,” said lead author Véronique Müller Campanile, DDS, a private-practice dentist in Geneva.

Researchers looked at data from 100 patients who had been previously treated for active periodontal therapy at Dr. Müller Campanile’s office. The patients had at least two years of maintenance periodontal therapy, including periodontal probing, oral hygiene reinforcement and plaque removal, and researchers customized the recall time for each patient. The patients received periodontal therapy and maintenance at the practice for two to 28 years, and the majority of patients had chronic periodontitis and were current or former smokers.

The reduction in periodontal disease markers was greater for patients with more frequent visits and who had received maintenance therapy for more years, according to the study, leaving researchers to assume there is no link between age and periodontal health research.

Periodontal complications, including recurrent active periodontitis, only accounted for 16 total lost teeth among patients, according to the study. Periodontal treatment and maintenance therapy also significantly reduced patients’ probing depth and bleeding on probing.

“This further corroborates, under real-life conditions in a dental practice, the power of regular maintenance care to reduce the incidence of residual pockets,” said Dr. Müller Campanile.

Learn more about this study in the Journal of Clinical Periodontology (2019); doi/10.1111/jcpe.13165.

Paulo G. Coelho, DDS, PhD

“We become what we behold. We shape our tools and then our tools shape us.” — Marshall McLuhan

During the second decade of the 2000s, it is well acknowledged that health-related professional practice has a multitude of aspects that include scientific, artistic, humanistic and economic components. Among these professions, dentistry by far exceeds others when it comes to innovation driving new clinical practice. The observation made by Marshall McLuhan is likely more impactful in dentistry than in other health-related professions. Historically, dentistry has become what it beholds, where clinicians and scientists shape new technology, and this new technology instinctively shapes the profession’s behavior toward the well-being of the patients.

Novel technology has been a major drive in clinical dentistry, but what we are currently observing worldwide is not only evolution but a disruptive development of dental practice due to digital workflow leading our profession to a new era, from diagnostics to full treatment execution. This issue of the Journal provides an overview of fundamental and practical aspects of the digital workflow and displays how such change allows for the immediate and near-future impact of 3D printed devices in restorative and regenerative dentistry as well as in surgical specialties such as oral and maxillofacial surgery and craniofacial surgery.

The first article, by Gisele Neiva, DDS, MS, MS, one of the pioneers of digital dentistry education in the world, demonstrates how computerized dentistry has become a multidisciplinary topic that has begun to be more formally taught in U.S. dental schools. This piece describes the beginnings of CAD/CAM and walks the reader through a journey of innovations that allow dentists to be more efficient and precise and how such technology may be integrated with additive manufacturing methods, such as 3D printing, to expedite and improve restorative and regenerative dental procedures.
Two articles communicate the challenges and advances currently encountered in restorative dental composites and ceramics and regenerative endodontics. The article concerning restorative materials by Luiz E. Bertassoni, DDS, PhD, et al. addresses key points, where subtractive and additive manufacturing technologies are contrasted in light of important restorative dentistry features such as geometric constraints for fabrication and technology compatibility as well as some of the important and rapidly evolving economic aspects of 3D printing restorative materials.

The article by Cristiane M. França, DDS, MS, PhD, et al. depicts examples of how successful 3D bioprinting of tissues and organs is being translated into regenerative dentistry. Through careful evaluation of published content and preliminary laboratory data, Dr. França describes the reasons why the use of 3D bioprinting methods for dental pulp tissue engineering and regenerative endodontics have remained limited but extremely promising for future patients in need and dental practitioners.

Lastly, the article by a craniofacial surgery group led by Roberto L. Flores, MD, describes how craniofacial surgery has seen an increased adoption of 3D printing technology in all steps of the reconstructive process. From sterilizable intraoperative 3D printed models to live bioprinting, 3D printing is helping surgeons refine existing treatment approaches, driving innovation in areas such as tissue engineering and vascularized composite facial alloplast implantation. Maxime M. Wang, BA, an MD candidate, unequivocally points out in the article that as surgeons identify clinical needs, 3D printing applications to plastic and craniofacial reconstruction will only continue to evolve.

Altogether, these articles will provide the Journal readership with the current state of the art as well as informing how digital workflow and 3D printing will shape the future of dentistry.
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CAD/CAM — The Future Is Here: Overview of Restorative Digital Footprint

Gisele Neiva, DDS, MS, MS

ABSTRACT Digital technologies have created a permanent imprint in restorative dentistry. It is no longer possible to conceive a restorative practice that is not at least minimally involved with digital processes. Computerized dentistry has become a multidisciplinary topic that begins to be more formally taught in U.S. dental schools. This article describes the beginnings of CAD/CAM and walks the reader through a journey of innovations that allow dentists to be more efficient, more precise and contemporary.

The digital revolution is here. Finally, digital processes are mainstream in everyday dentistry as they improve workflows from the average clinician to the large practice-based networks. Digital dentistry is now part of the curriculum of the leading dental schools in the country, and new graduates are generating an unprecedented digital momentum as they aspire starting their professional careers in offices that embrace digital technologies for dental applications.

The purpose of this article is to elucidate the current state of digital dentistry, provide a background on the several digital processes that enhance modern dentistry and dive into the most recent innovations in the field of computerized dentistry, from image acquisition to 3D printing.

Digital Beginnings — Chairside Systems

Computer-aided design/computer-aided manufacturing (CAD/CAM) had its origins in the aircraft and automotive industry in the 1950s through computer modeling, simulation and the use of numerical control technologies to integrate design and manufacturing. CAD/CAM integration between design and manufacturing allowed the computer designers direct control over the manufacturing process, which ensured a final product that better achieved its intended outcome.

CAD/CAM was first mentioned in dentistry in the 1970s by Francois Duret, DDS, DSO, PhD, but early reports were primarily experimental. However, there was always a focus on the potential clinical applications of the technology. The first report of clinical application of CAD/CAM in dentistry was in the late
1970s by Heitlinger and Rodder, who fabricated a stone model by using a milling technique. The model was then used for dental restoration fabrication. In the early 1980s, the collaboration between a Swiss prosthodontist, Werner Mörmann, DDS, and an electrical engineer, Marco Brandestini, PhD, at the University of Zurich in Switzerland led to the first commercialized CAD/CAM system for chairside applications. They explored the direct clinical application of CAD/CAM with the restoration fabrication approach by utilizing a single picture to mill the internal surfaces of an inlay. The first CAD/CAM prototype was introduced a few years later in 1983 at the Granciere Conference in France. A couple of years after that, the first CAD/CAM crown was designed, milled and installed in a live demonstration by Dr. Duret and collaborators at the Congres Association Dentaire Française de Paris in 1985. The Chairside Economic Restoration of Esthetic Ceramics (aka CEREC) system was introduced shortly after that by SIEMENS AG, Germany (now Dentsply Sirona) allowing dentists to fabricate same-day ceramic inlay restorations as an alternative treatment to amalgam restorations.

Around the same time, the price of gold had increased and nickel-chromium alloys had been introduced as a substitute material, causing a drastic increase in reported cases of metal allergies. In an effort to provide an alternative treatment option for patients with a known allergy to nickel, Mats Andersson, DDS, PhD, of Sweden attempted to fabricate titanium copings by spark erosion for fabrication of composite veneered restorations, which was another milestone in dental CAD/CAM technology, that led to the introduction of the Procera system by Nobelpharma (now Nobel Biocare, Zurich) in 1983.

In 1988, Dr. Duret and collaborators described the Duret CAD/CAM system, however the system was very complex and required a large setup that prevented it from making a significant impact in the market. Around the same time, several Japanese universities started to research and develop CAD/CAM systems that eventually made it to the Japanese domestic market. Other groups of collaborators led by Diane Rekow, DDS, PhD, of the University of Minnesota and Reggie Caudill, PhD, of the University of Alabama, among others, were also developing CAD/CAM systems that became commercially available but did not achieve widespread use in the American market.

An increasing number of chairside systems have been introduced since then. The E4D Dentist System (D4D Technologies, Richardson, Texas) was introduced in 2008. The system was composed of an intraoral laser scanner, a mobile design center with DentaLogic software and a milling unit with a dedicated CAM computer. In the meantime, the CEREC system has gone through constant evolution and newer versions of the system have progressively been introduced with parallel software and hardware advances such as CEREC 2 (1994), CEREC 3 (2000), CEREC 3D RedCam (2003), CEREC AC BlueCam (2009) and CEREC AC Omnicam (2012), which was the first color intraoral scanner.

The CS 3500 intraoral scanner was introduced in 2013 as part of the Carestream system, which also comprehended in-office design with CS Restore software and in-office fabrication with a CS 3000 milling unit. Even though the Carestream system had limited chairside capability, the CS digital files could alternatively be uploaded to a dental laboratory via CS Connect as they are compatible with a number of commercial laboratory design programs such as 3Shape (3Shape, Copenhagen, Denmark) and Exocad (Exocad Gmbh, Darmstadt, Germany). In 2017, Planmeca introduced Emerald intraoral camera, PlanCad 6.0 Design Center Software and PlanMill 40s (Planmeca, Helsinki). And the latest innovation in chairside CAD/CAM systems has recently been introduced by Dentsply Sirona: the CEREC Primescan AC (Figure 1) with intelligent automations incorporated in software version 4.6 (2019).

**Intraoral Scanners (IOS)**

An alternative to chairside systems that focuses primarily on data acquisition is the intraoral scanner (IOS). Dentists who choose not to be involved with restoration design and manufacturing but still would like to use digital workflows may decide to replace analogue impressions by digital scans using IOS. A significant number of IOS have been introduced since the late 2000s, and they have constantly been updated and improved. The intraoral cameras have become more ergonomic and faster in image processing, and the use of anti-reflective powder to reduce glare is no longer necessary. The scans can be edited until all necessary data is captured. The data are stitched together seamlessly simply by restarting from a previously recorded area. Once the scan is complete, the data can be exported in Standard Tessellation Language (.stl) format to a model manufacturing facility for model production or directly to the dental laboratory for restoration fabrication.
Some IOSs have added features such as color rendition and spectrophotometer capability for shade selection.

A few of the latest IOSs include iTero Element 5D (Align Technology, San Jose, Calif.), 3Shape Trios 4 (3Shape) and 3M True Definition Scanner (3M) (FIGURE 2). The 3Shape Trios 4 is the latest innovation from 3Shape. It has two new features for caries detection, infrared transillumination and fluorescence, in addition to other functions already present in previous versions of the scanner such as shade selection and fast color image acquisition. It is compatible with lab processing software such as Dental System CAD/CAM Design, Implant Studio and 3Shape Ortho software as well as the chairside software 3Shape TRIOS Design Studio for same-day restorations using a third-party mill. The iTero Element 5D is the most used scanner for orthodontic applications and includes unique features such as near-infrared caries diagnosis and timeline comparisons of caries progression, treatment planning of orthodontic aligners with Invisalign Outcome Simulator and Progress Assessment software. The 3M True Definition Scanner was the first IOS to offer a mobile scanner that operates solely from a proprietary tablet computer. It is also available in a cart version and uses 3D-in-motion video technology.

The in vivo accuracy and precision of digital methods have been evaluated by several studies. Ender and Mehl compared eight digital impression systems for accuracy and precision including the 3M True Definition Scanner (3M), iTero (Align Technology), 3Shape Trios (3Shape) and Trios Color (3Shape) as well as CEREC BlueCam (Software 4.0), CEREC BlueCam (Software 4.2) and CEREC Omnicam (Dentsply Sirona, Charlotte, N.C.). The impressions were superimposed within each test impression group, for each patient, using CAD software (Geomagic Qualify 12, 3D Systems, Rock Hill, S.C.). The authors concluded that despite significant differences, all of the digital impression systems tested were capable of producing quadrant impression with precision that was clinically acceptable.15 Similarly, Hack and Patzalt measured the ability of six intraoral scanners to accurately capture a single molar abutment tooth in vitro. The scanners tested included iTero (Align Technology), 3M True Definition Scanner (3M), PlanScan (Planmeca), CS 3500 (Carestream), 3Shape Trios (3Shape) and CEREC Omnicam (Dentsply Sirona). A master typodont model of a single crown preparation was scanned with a highly accurate industrial benchtop scanner and the digital file was compared to the digital scans of the intraoral scanners using a CAD software program (Geomagic Qualify, 3D Systems). Precision was measured by superimposing the benchtop scanner digital file onto the digital files recorded by each scanner and evaluated for 3D deviations. The authors concluded that all scanners investigated produced clinically acceptable accuracy.16 Several other studies are mostly in agreement that accuracy and precision are comparable among the systems tested, especially for quadrant impressions. In contrast, most chairside CAD/CAM systems and intraoral scanners are not as accurate or precise for full-arch digital scans and distortions can be easily identified.17 Nevertheless, no current studies contrast the most recent technologies available. This demonstrates that dental CAD/CAM is an extremely volatile field and that technology evolves faster than the literature can record.

Components of CAD/CAM Systems

Dental CAD/CAM systems comprehend three distinct processes: data acquisition, CAD and CAM.

The data acquisition process entails recording the geometry of the teeth and interarch relationship by use of an intraoral optical scanner (either by confocal laser scanning or active wavefront sampling). Alternatively, this may be accomplished by scanning a stone model using a benchtop scanner (by projection of a light pattern).18 The scanner transforms image files into digital data in .stl file format, which can be processed by the designing software.

CAD is done by a software that processes the digital data and generates a digital prototype of the final contour of the restoration. The design of the 3D contours of the restoration by the CAD software can be represented by a combination of geometric shapes that can be translated into equations in a process known as “triangulation.” The CAD output is also in .stl file format. CAM can be done either by subtractive milling or the additive 3D method.

CAM Processing Variants

Subtractive milling is a CAM process that generates the restoration by removing material from a prefabricated block through a computer-generated path on a mill or grind with the use of diamond or carbide burs. The processing method depends on how the burs are applied to the milling block. In 3-axis machining, the burs move in two different axes as the block advances in different speeds preset by the operator. More complex shapes...
require either 4-axis or 5-axis milling where the burs move in translation as well as rotational patterns. The quality of the restoration does not improve with an increased number of processing axes, but a more detailed restoration may be obtained.

In addition, milling may be accomplished either dry or with water cooling, depending on the material to be processed. Dry processing is mainly used for milling zirconia and is accomplished by carbide burs. This eliminates the need for a drying cycle and shortens the overall processing time for the restoration. Most other chairside CAD/CAM materials are processed via wet grinding where diamond burs are cooled with a liquid spray. This avoids heat-induced damage to the restorations. Nevertheless, subtractive milling results in wasted material and not all materials can be milled. The 3D additive method can overcome these shortcomings.

Additive methods are also known as “rapid prototyping” or “3D printing.” There are seven additive methods for CAM, but only four are used in medical fields: stereolithography, material extrusion, binder jetting and powder bed fusion. Stereolithography is a CAM method also known as “vat polymerization,” where a tank of photocurable liquid resin is light cured layer by layer according to the computer coordinates. This is generally applied for 3D printing of digital models. In the CAM process “material extrusion,” the printing material is selectively dispensed through a nozzle and cured layer by layer by computer directs. Binder jetting comprehends selective deposition of a liquid bonding agent onto a reservoir of powder material that is also cured by layers. Lastly, powder bed fusion is a CAM process that uses thermal energy to selectively fuse regions of a bed of powder material. In general, 3D printing enables manufacturing of materials that cannot be milled. With the continuous development of functionally graded materials, it is expected that 3D printing will become the main CAM manufacturing method in the future.

**Virtual Articulators and Digital Facebows**

Even though a virtual articulator is an integral part of the CEREC system, digital facebows are not yet mainstream, therefore this function tends to not be used on a regular basis and average values are generally used for digital restoration design. However, jaw tracking devices are already available, mainly as an integrated solution to cone beam computerized tomography (CBCT). Galileos CBCT (Dentsply Sirona) (FIGURE 3) and SICAT Jaw Motion Tracker can be merged with CEREC data into SICAT Function (FIGURE 4), allowing integration of motion data in CEREC, which enables restoration design based on realistic mandibular dynamics.

Similarly, Planmeca has the 4D Jaw Motion software that uses CBCT images and enables real-time visualization of mandibular movements. The system tracks and visualizes jaw movements with the Planmeca ProFace camera feature of Planmeca CBCT. Captured 3D images are displayed in the Planmeca Romexis imaging software, allowing immediate diagnostics of temporomandibular disorders, mandibular movement analysis and articulator programming as well as preoperative planning and postoperative treatment verification.

Another option to record mandibular kinetics has been described by Gutman and Keller. GnathTech TMJ Digital Recording system consists of a jaw tracking device and virtual articulator package that can be interfaced with existing dental CAD/CAM systems. It allows the dentist to record and analyze the real-time trajectory of the lower jaw movement as well as the temporomandibular joint.

Alternatively, several systems rely on mechanical facebows and casts that are mounted on articulators and then scanned on benchtop scanners.
AI is also a trend in dental technologies. Primescan (Dentsply Sirona) (FIGURE 5) is the first intraoral camera with AI. It has a “smart pixel sensor” with resolution five times higher than any other intraoral camera currently available and “intelligent processing” that filters and compresses the data at once generating 1 million 3D data points per second for a precise output.²⁵ AI is definitely going to become mainstream in the CAD/CAM industry going forward.

Lastly, as CAD/CAM technologies evolve, dental materials for CAD/CAM applications must evolve at a matching rate. Currently, all chairside CAD/CAM systems rely on subtractive milling for restoration fabrication. As printers become more efficient and able to print objects of finer precision, it is imperative that printable materials improve in quality, appearance, speed of processing and longevity in the oral environment. 3D printed restorations are already a reality and should continue to evolve in order to match and surpass the physical and mechanical characteristics of their milled counterparts for a more economical and sustainable workflow.

Conclusions and Future Perspectives

This article reviewed the background of CAD/CAM dentistry, described the current status of dental technologies and opened the door for future advancements in the field. Currently, all intraoral cameras and IOS are only capable of recording what is captured in the field of view of the camera. Future directives may explore the use of ultrasonic waves to record margins through tissue, saliva and even blood.²⁴ However, if CAD/CAM systems do incorporate this technology, the dentist would still have to manage the soft tissue prior to resin cementation of the restoration. Therefore, unless tissue retraction and hemostasis can evolve parallel with the implementation of ultrasonic technology, this would be a less impactful advance.

On the other hand, artificial intelligence (AI) is already influencing the interaction between people and technology in several fields. Computerized systems can be programmed to “learn” patterns, identify frequent trends and act systemically in response. The most trivial example of that is the face recognition feature of smartphones; it is perplexing how AI expedites several smartphone processes, from secure hands-free login to money transactions.

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Current and Future Applications of 3D Bioprinting in Endodontic Regeneration — A Short Review

Cristiane M. França, DDS, MS, PhD; Ashley Sercia, BS; S. Prakash Parthiban, PhD; and Luiz E. Bertassoni, DDS, PhD

ABSTRACT 3D bioprinting has emerged as an exciting tool for regenerative medicine and tissue engineering applications. Several examples of successful 3D bioprinting of tissues and organs have been provided in the literature, including many in regenerative dentistry. Despite significant progress, the use of 3D bioprinting methods for dental pulp tissue engineering and regenerative endodontics has remained limited. Here we offer a brief overview of how 3D bioprinting may be relevant to the future of regenerative endodontics.

Dental pulp regeneration has emerged as an exciting method in clinical dentistry in the past decade. As such, there is a growing need for regenerative treatments that will advance current endodontic therapies. An estimated 22.3 million endodontic procedures are performed every year in the U.S.,¹ which represents a large section of the $117 billion annual expenditure associated with dental care in the U.S.² Despite their outstanding success rates for a wide variety of endodontic procedures, current endodontic materials largely fail to mimic the composition, physical properties and regenerative capacity of the native pulp, therefore, the development of regenerative materials and therapies has been a focus of extensive research in the field. Bioactive endodontic cements, such as calcium hydroxide (Ca(OH)₂), mineral trioxide aggregate (MTA) and Biodentine are used for various

Authors

Cristiane M. França, DDS, MS, PhD, is a research associate in the division of biomaterials and biomechanics in the department of restorative dentistry at Oregon Health & Science University School of Dentistry. Her research focus has been on the effects of laser therapy in wound healing of different tissues and different aspects of tissue engineering and regenerative medicine, including dental pulp, vascular and bone regeneration. Conflict of Interest Disclosure: None reported.

Ashley Sercia, BS, is a student in the DMD program at Oregon Health & Science University and a researcher at the Bertassoni Lab. Her major research interests include tissue engineering, biomaterials and regenerative dentistry. Conflict of Interest Disclosure: None reported.

S. Prakash Parthiban, PhD, is a research associate in the division of biomaterials and biomechanics in the department of restorative dentistry at Oregon Health & Science University School of Dentistry. His major interests are hard tissue mineralization, vascular and developmental biology. Conflict of Interest Disclosure: None reported.

Luiz E. Bertassoni, DDS, PhD, is an associate professor at Oregon Health & Science University. He holds appointments at the department of restorative dentistry, the OHsu Center for Regenerative Medicine, the department of biomedical engineering and the Cancer Early Detection Advanced Research center (CEDAR) at the Knight Cancer Institute. Dr. Bertassoni leads a multidisciplinary research group working on various aspects of biomaterials and tissue engineering. Conflict of Interest Disclosure: None reported.
clinical procedures where the dental pulp is injured or indirectly affected. However, despite the known ability of these materials to elicit tertiary dentin formation in vital young teeth, they are not biodegradable, do not contain cell adhesive ligands and have poor ability to have their physical properties adjusted to address patient/case specific needs, which limit their ability to elicit controlled and predictable cell-mediated tissue response. Moreover, in events where inert materials are used to replace the entire pulp structure, the tooth vitality and biological response are completely and permanently depleted, potentially leaving the tooth structure weakened and prone to fracture. Even though these strategies have proven clinical merit, opportunities exist to refine the field of endodontics by introducing a more regenerative approach.

The current American Association of Endodontists’ Glossary of Endodontic Terms defines regenerative endodontics as “biologically based procedures designed to physiologically replace damaged tooth structures, including dentin and root structures, as well as cells of the pulp-dentin complex.” Efforts to induce regeneration of the dentin-pulp complex were pioneered by Nygaard-Östby in 1961 in an original study that investigated the role of blood clots in endodontic therapy. Briefly, periapical tissue bleeding was induced to fill the pulp chamber with blood clot in canine (n = 8) and human teeth (n = 17), then the cervical part of the canal was closed with gutta-percha and Kloroperka N-O. After observation periods ranging from 13 days to 3.5 years, teeth were extracted and processed for histological examination. It was found that all cases were asymptomatic, and microscopically, all root canals contained viable cells showing a gradual substitution of the fibrin clot into granulation tissue and finally into fibrous connective tissue. However, the extent of newly formed tissue inside the root and pulp chamber, as well as the composition, varied considerably from case to case, and three cases showed dental pulps populated by undesired cells as dense inflammatory infiltrate. In general, the findings were promising, but the high variability on the results, evidence of root resorption and lack of an odontoblast layer close to the dentin, indicated that the blood clot alone would not be sufficient to induce complete dental pulp regeneration. The author pointed out that young teeth with open apex and necrotic pulps showed subsequent apical development after the use of this protocol and this could be the most encouraging indication for blood clot use in endodontics, paving the way for future revascularization procedures.

Ten years later the same group published a series of clinical cases where endodontic treatment using blood clot induction was used in vital (n = 35) and necrotic (n = 12) mature human teeth. The follow-up period ranged from 3.5 months to three years before the teeth were extracted for histological evaluation. Again, a significant variability in the outcomes was observed and described as fibrous tissue occupying either the entire or part of the root canal in 28 out of the 35 teeth from the vital group or no tissue formation in any of the formerly necrotic teeth. In 2001, the paradigm that necrotic pulp could not be revascularized using blood clots was broken by Iwaya and collaborators. After this, an incremental number of clinical cases using variations of this technique were reported.

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<tr>
<th>Year</th>
<th>Event</th>
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<tr>
<td>1961</td>
<td>Demonstrated that blood clot promotes tissue ingrowth into pulpectomized root canals of dogs and humans.</td>
<td>Nygaard-Östby</td>
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<td>1971</td>
<td>T. Yamamura Showed that pulpal cell differentiation and ability to elaborate hard tissues depend on the matrix environment.</td>
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<td>1985</td>
<td>Ivowa et al. Case report using blood clot induction to treat immature teeth with necrotic pulp and apical periodontitis. The term revascularization was used.</td>
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<td>2001</td>
<td>Several groups Isolation of stem cell from different sources in the oral environment as tooth germ, dental follicle, salivary gland, apical papilla, inflamed periapices, exfoliated deciduous teeth, periodontal ligament, bone marrow, oral epithelium, gingival-derived and periodontal.</td>
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<td>2002</td>
<td>Huang and Lin Proposed a change in the term revascularization to revitalization.</td>
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<td>2003</td>
<td>Rosa et al. Used a hydrogel scaffold and stem cells to engineer dental pulp tissue in full-length root canals in an immunodeficient mice model.</td>
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indicating that patients with open apex teeth could benefit from revascularization procedures. This culminated with the publication of an optimized protocol using a triple antibiotic paste in 2004, which has been broadly adopted in current days.\footnote{11}

Based on the advances in tissue engineering, cell biology and biomaterials,\footnote{12} in 2007 the American Association of Endodontics launched a review explaining the term “regenerative endodontics,” its goals and a description of the potential approaches available at that time to regenerate pulp-like tissue, as follows: root-canal revascularization, postnatal (adult) stem cell therapy, pulp implants, scaffold implants, three-dimensional cell printing, injectable scaffolds and gene therapy.\footnote{13}

Since 2011, in vivo studies in animal models have demonstrated that it is possible to regenerate dental pulp in mature teeth using autologous hDPSCs transplantation in animal models.\footnote{14} A series of successful reports demonstrating some level of dental pulp and dentin regeneration are summarized in Figure 1. A seminal study by Xuan et al. in 2018 showed that the implantation of autologous dental stem cells from deciduous teeth was able to regenerate dental pulp with the odontoblast layer, blood vessels and nerves in animal models. Subsequently, the authors conducted a randomized clinical trial in 30 young patients with tooth trauma providing unequivocal evidence that autologous transplant of human deciduous stem cell sheets expanded from deciduous teeth and when placed into the traumatized tooth was able to guide dental pulp regeneration toward clinical outcomes as increased root length, reduced apical foramen the width and clinical positivity to sensitivity tests when compared to conventional apexification treatment.\footnote{15}

Interestingly, the use of hydrogel-based biomaterials is common to the far majority of materials-assisted examples of successful dental pulp regeneration in the literature. Hydrogels consist of highly hydrated polymer networks that can be engineered with similar composition and properties to the tissue of interest and can be synthesized with controllable chemistry that allows for specific cell attachment and response.\footnote{16,17} For instance, Sakai et al. showed in 2010 that stem cells from human exfoliated deciduous teeth (SHED) embedded in poly-L-lactic acid (PLLA) scaffolds differentiated into functional odontoblasts that generated tubular dentin, as determined by tetracycline staining and confocal microscopy when tooth slices were implanted subcutaneously.\footnote{18} Rosa et al. showed even more substantial regeneration in vivo using full-length root canal models of SHED-encapsulated collagen and PuraMatrix hydrogels.\footnote{19} More recently, our group developed hydrogels that can be photocrosslinked using standard dental curing lights\footnote{20} and can be used to biofabricate microconduits in the core of empty root canals, which formed vascular capillary-like structures after seven days from injection of human endothelial cells in vitro.\footnote{21} One of the greatest advantages of hydrogels is their ability to undergo patterning on the microscale using a variety of biofabrication methods. We have reviewed a wide range of possibilities in a recent paper.\footnote{16} One of the more exciting developments in hydrogel biofabrication in recent years was the development of 3D bioprinting tools. A wide range of applications of 3D bioprinting has been reported in many areas of medicine and regenerative engineering to date, and we encourage the reader to refer to a recent review where we cover the specific uses of bioprinting in regenerative dentistry.\footnote{22} 3D bioprinting as applicable to endodontic regeneration, nevertheless, has seen much slower progress. Therefore, to stimulate thinking and outline recent advances in this area, we provide a brief overview of different 3D bioprinting technologies and point toward possible applications for these methods in dental pulp regeneration in future years.

**Bioprinting Methods**

Currently, there is an ever-expanding range of bioprinting methods, and it is difficult to pinpoint precisely the categories that accommodate all 3D printing modalities used for tissue regeneration. Therefore, for simplicity, in the following section we...
describe bioprinting methods that fall under the broad umbrellas of extrusion-based systems, laser and light lithography and inkjet 3D printing (FIGURE 2).

Furthermore, we refer to 3D bioprinting as the methods that use cells or cell-laden biomaterials as the printing inks, whereas 3D printing of cell-free biomaterials is referred to as 3D printing only.

**Extrusion-Based Bioprinting**

Extrusion-based 3D printers dispense bioink, typically in the form of a fiber, in a continuous process through a print head in a layer-by-layer manner. The components of extrusion-based printers usually include a fluid-dispensing system for extrusion and an automated robotic system for X-Y-Z positioning of the material. To print the required shape, 3D parameters are first fed into computer-aided design (CAD) software to create a file that the printer uses to dispense the material in a site-specific manner. The advantage of this method is that even medical images like MRI and CT scans can be converted. To dispense the bioink, the print head is usually controlled by a pneumatic-, mechanical- or solenoid-based system. Pressurized air is used in the pneumatic system while the mechanical extrusion uses a piston or screw to drive the dispensing unit. Of these, piston-driven units give good control over the flow of bioink through the nozzle, while the screw is good for high-viscosity bioinks. Solenoid printers use electrical pulses to manipulate the valve, thereby controlling the flow of bioink through the nozzle.

With respect to cells, this method shows good cell viability in general, however, this has been shown to be dependent upon shear stresses, nozzle diameter and the pressure of the dispensing unit. Extrusion-based bioprinting is the most ubiquitous method used in bioprinting as it can print a variety of bioinks including hydrogels, cell aggregates or spheroids and decellularized matrix components. Despite these advantages, this method is limited by the resolution of its printing, which usually ranges from 100–1,000 µm.

**Laser-Based Bioprinting**

The demand for high-resolution bioprinting paved the way to the adaptation of laser-based printing from other fields of manufacturing to the field of cell biology and biomanufacturing. An example of such an adaptation is the method called laser-induced forward transfer (LIFT), which is used in computer chip fabrication for high-resolution patterning of metals. To print the material, LIFT uses a laser beam and a donor ribbon composed of the printable material. A transport layer beneath the donor ribbon absorbs and transfers the laser energy creates a high-pressure bubble in the donor ribbon that transfers the donor material onto a collecting substrate. For bioprinting, the ribbon contains the bioink (cells or cell-laden materials) that gets deposited as droplets onto the substrate. Thus, by moving the substrate or laser, the patterning of the material can be performed on the collecting substrate. For creating 3D structures, the same process is repeated in multiple
layers. One of the remarkable effects of this method is that it can print with a resolution of nearly a single cell per droplet. The lack of a nozzle further adds to its advantage as clogging issues seen in other methods of printing are negated. Cells are also highly viable (> 95%) and the method allows precise positioning of cells within 5 µm. On the downside, this method requires a bioink with fast gelation kinetics owing to the high resolution of the printer and also a fast-moving stage for fabrication. Moreover, printing of large-scale tissue constructs is nearly impossible due to the slow printing process and the requirement to keep cells viable as the slow, layer-by-layer deposition process takes place.

**Light (Lithography) and Digital Light Processing (DLP) Bioprinting**

Sterolithography and digital light processing bioprinting methods use a solid freeform technique employing photosensitive monomer blends as the scaffold material. The monomer ink is poured onto a reservoir tray and is irradiated either from the bottom or from the top with either ultraviolet or blue light. This allows irradiation of the photocrosslinkable monomer, resulting in curing of a thin layer of the material. Further exposure of the monomer to light in a layer-by-layer fashion results in the build-up of 3D constructs. This printing method was originally used to fabricate cell-free structures, but after the availability of new photocurable polymers, it is widely used in the bioprinting of cell-laden scaffolds. Methacrylated materials are highly suitable for this method as they allow cell-friendly visible light as a curing source. This method can produce 3D structures with a Z resolution down to 10 µm and X-Y to a nominal resolution of ~40 µm.

**Droplet-Based Bioprinting**

Inkjet-based bioprinters create 3D biological structures via drop-by-drop dispensing of the bioink. Droplet-based bioprinting can be categorized into direct ink-jetting, acoustic-droplet-ejection and microvalve bioprinting, to name a few. Inkjet bioprinting typically utilizes cartridge-based delivery systems to create conventional 2D structures. 3D structures can be produced by having the Z-component and printing the structure one layer at a time. Commercially available cartridges of inkjet printers can also be used for this kind of printing, as distinct bioinks can be loaded onto separate cartridges to create computer-controlled structures. However, the shear stress on the bioinks and cells are considerable and careful optimization of the system needs to be done. Based on how the droplets are ejected, inkjet bioprinting can be further subdivided into continuous, drop-on-demand and electrodynamic methods. Acoustic bioprinting uses a piezoelectric material to create acoustic waves that pull the droplets from the pool by overcoming the surface tension of the liquid. In microvalve bioprinting, electromechanical valves are used to create droplets. Resolution of 50–100 µm can be reached from droplet-based bioprinting, however, clogging issues and a narrow range of viscosities end up limiting the usefulness of an inkjet bioprinter for the fabrication of clinically meaningful tissue constructs.

**Applications of Bioprinting in Regenerative Endodontics and Dental Pulp Tissue Engineering**

Application of 3D bioprinting methods for fabrication of dental pulp-like tissue constructs is difficult. This is primarily due to the challenging morphologies and size of root canals and the complexity of pulp tissue in native teeth, which would need to be replicated in the lab if one intends to fully 3D print the dental pulp prior to implantation. Different from systemic organs or larger tissue structures that have been successfully bioprinted to date, the dental pulp conforms to the semiconical and branched morphologies of root canals. These range from a few microns in diameter at the root apex up to a few millimeters in the pulp chamber. Thus, by definition, the dental pulp is a small, complex architecture that is difficult to replicate with current 3D bioprinting systems given their limited resolution. Moreover, and of greater significance, the ability of bioprinting a pulp-like tissue would depend on the ability of the printing system to replicate the multilayered structure of the pulp tissue when analyzed from the pulp-dentin interface toward the core of the tissue. For instance, the pseudopalisade structure of the odontoblast layer, which makes its way directly into the tubules within the dentin tissue, is positioned immediately adjacent to the dentin wall. This layer is separated from the highly cellularized core of the pulp tissue by the so-called cell-free zone. Next, the vasculature is denser in the core of the tissue and branches out as it increases in complexity toward the pulp-dentin interface. Each of these structures measures approximately 50–100 µm or less, which fall below the current resolution range of most available bioprinters, especially the more widespread extrusion-based systems. Nevertheless, current improvements in printing resolution may
were able to demonstrate that when these hydrogels were loaded with odontoblast-like cells in 3D, cells remained viable for at least seven days after 3D geometries were fabricated and cell differentiation was stimulated by the presence of the dentin-derived molecules (FIGURE 3).

The application of these fiber-based cell-laden biomaterials for fabrication of pulp-like tissue constructs for clinical utilization remains distant. However, the ability of patterning tissue structures in a well-defined and controllable manner in vitro enables the development of intricate model systems that may be utilized to better understand physiologic and disease processes with greater accuracy than what is currently possible. This, perhaps, represents the greatest advantage of current printing systems and how they may be applied for dental pulp regeneration in the short term (FIGURE 4A).

Despite the significant limitations of fabricating small and complexly shaped tissues using an extrusion-based system that has a maximum resolution in the order of several tens of microns, the use of extrusion 3D printing systems in regenerative dentistry has shown encouraging results. In a recent report, our group demonstrated the development of a dentin-derived bioink that was fabricated by combining an alginate hydrogel prepolymer with demineralized and processed human dentin matrix, which contained a wide range of dentin noncollagenous proteins.27 We were able to demonstrate that when these hydrogels were loaded with odontoblast-like cells in 3D, cells remained viable for at least seven days after 3D geometries were fabricated and cell differentiation was stimulated by the presence of the dentin-derived molecules (FIGURE 3).

Recent examples of 3D bioprinted tissues that are present in the craniofacial space have been reported with outstanding success. For instance, in 2018 Murphy et al. reported on the fabrication of fully 3D printed cartilage, bone and muscle, all using cell-laden hydrogels that were dispensed using an extrusion-based bioprinting method.44 Similar to the previous description proposed for dental pulp bioprinting, these hydrogels were dispensed over a sacrificial (degradable) support, which allowed the cell-laden hydrogels to be patterned with the desirable 3D shape, cultured in vitro and implanted to show remarkable similarities to the native tissues. Using extrusion-based printing systems, several other examples of 3D printing of blood capillaries and osteo/odontogenic materials have been proposed.46–47 These illustrate the rapidly emerging solutions to fabricate building.
blocks that make up the dental pulp, and that may inspire the regeneration of entire pulp tissue using 3D printing-based approaches in the future. In fact, a recent report by our group on the fabrication of prevascularized root canals used a 3D printing inspired method to engineer blood capillaries across the length of a root canal model. In that report, we showed that the steps to form a blood capillary in the tooth followed the same principles used to 3D print blood vessels within hydrogels. Overall, these methods illustrate how the field is slowly moving toward more feasible ways of enabling dental pulp tissue engineering using 3D bioprinting methods.

**Bioprinting of Prepatterned and Injectable Microgels**

Another interesting approach that has been developed recently and appears to address other aspects that are relevant to pulp regeneration despite the lack of site-specific control is the bioprinting of micropatterned hydrogels or microgels. In this method, which draws inspiration from hydrogel patterning via other mechanisms of microfabrication, researchers can use a DLP bioprinter to fabricate microscale scaffolds that can be loaded with different biologics (cells, growth factors, etc.) and that are 3D printed in high-throughput in a short period of time (Figure 4B). Because DLP 3D printing allows for fabrication of cell-laden hydrogels that are as small as 150 µm in width and length, and theoretically as little as 25 µm in height, these microgels can be injected directly into the root canal space using a regular syringe needle due to their small size. As described above, DLP bioprinting works by exposing a layer of the monomer of interest to light only once, and provided that the set scaffold height has the same dimension of the build-layer height, microgels can be fabricated with a single light exposure, which allows for the fast fabrication. Given that hydrogels can be photocrosslinked in as little as three seconds without affecting cell viability, these methods represent an extremely fast process of biofabrication that may be suitable for regeneration of the dental pulp in root canals. The fact that these hydrogels do not form a monolith, as traditional materials that are currently injected into the root canal space do, allows cells to quickly migrate and infiltrate the site and stimulate faster regeneration. Of note, this method allows for improved cell-homing both when the gels are fabricated in the absence of cells or when cell-laden hydrogels are used because diffusion of nutrients and oxygen to cells is improved, which in turn should enhance the metabolic activity of the embedded cells.

**3D Printing of Patient-Specific Regenerative Bioreactors**

Another possible application of 3D printing to regenerative endodontics is the concept of 3D printing patient-specific bioreactors. In this method, the core principle of bioprinting may be missed because living cells are not actually printed. However, it may represent an enabling methodology to achieve improved biological outcomes. In such methods, the traditional steps of bioprinting tissues are followed with small modifications. For instance, the root canals can be imaged using advanced radiology methods (µCT, MRI) to create the digital imaging and communications in medicine (DICOM) files with patient-specific architectural data. The DICOM files would then be used to create the computer-aided design that will inform the printer how to fabricate the actual tooth structure, which will effectively be used as a biocompatible mold made out of a biocompatible polymer. After fabrication of this 3D mold, a cell-laden hydrogel (or microgel) can be injected into the 3D printed root canal space (Figure 4C) and the injected cell-laden material can be cultured in vitro for as long as necessary under tissue culture conditions. After maturation of the pulp-like tissue, the whole construct can be transplanted into the patient’s root canal space, with the expectation that the patient-design may stimulate a faster regeneration. Examples of this method remain to be fully developed and studied, but preliminary studies in our laboratory demonstrate that this feasible.

**Conclusion**

In conclusion, while 3D bioprinting approaches have not been developed to their full potential for dental pulp regeneration, there are sufficient examples in the literature that point toward their usefulness in the toolbox of dental pulp tissue engineers and perhaps dental clinicians in the future. Much research remains to be developed to enable effective 3D bioprinting of pulp-like tissues in the lab. Nevertheless, progress in other areas of biomedical engineering will pave the way for the utilization of 3D bioprinting in regenerative endodontics and dental pulp tissue engineering with the same success that they have found in other areas of regenerative medicine.

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3D Printing of Restorative Dental Composites and Ceramics — The Next Frontier in Restorative Dentistry

Luiz E. Bertassoni, DDS, PhD

ABSTRACT While 3D printing of materials for nonrestorative use has become a common finding in dentistry, chairside printing of restorative materials is still in its nascent years. Here we discuss the characteristics that make 3D printing an advantageous fabrication method for restorative dentistry. We discuss examples of printed dental resins, composites and ceramics and highlight the applications that will pave the way for the emergence of 3D printing as a mainstream method in restorative dentistry.

AUTHOR Luiz E. Bertassoni, DDS, PhD, is an associate professor at Oregon Health & Science University. He holds appointments at the department of restorative dentistry, the OHSU Center for Regenerative Medicine, the department of biomedical engineering and the Cancer Early Detection Advanced Research center (CEDAR) at the Knight Cancer Institute. Dr. Bertassoni leads a multidisciplinary research group working on various aspects of biomaterials and tissue engineering.

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The field of 3D printing has expanded at an extraordinary speed and has established itself as a mainstream technology in virtually every field in the past decade. From 3D printed shoes to entire buildings, houses and human organs, one could argue that virtually anything is “printable” since the inception of 3D printing in day-to-day life. Dentistry has benefited tremendously from this new wave of technology because manual fabrication of materials in 3D is part of the daily routine of the dental practitioner, and many of the technologies that have been used in dentistry for a number of years (i.e., CAD/CAM) are built on similar fundamental concepts to those that support the foundations of 3D printing — that is, 3D design and fabrication. A significant percentage of the common knowledge that has dominated this area can be attributed to the boom that 3D printing technologies have seen in the popular media, most significantly after the expiration of several patents that protected the intellectual property associated with 3D printing back in the early 2000s. With such a rapid expansion and the free-flowing volume of information in the unspecialized media, much of the hype that has been geared toward the potential utilization of 3D printing in the medical and dental fields has been somewhat poorly rationalized to clinicians and patients. Consequently, many are left to wonder why 3D printing has often been referred to as the next industrial and medical revolution. In this manuscript, we try to elucidate some of the overarching concepts that...
joyce the hype the 3D printing industry has received over the past decade. We also give examples of how these individual characteristics may be advantageous, if not transformative, over subtractive methods in the scope of clinical restorative dentistry.

Geometrical Constraints

In 3D printing, there are virtually no limits to the internal geometrical constraints of a built part. A 3D material may be fabricated with intricate internal geometries and arbitrary angles, for instance, as the framework of a dental bridge or a crown. This can all be performed based on a rationally designed architecture to better distribute the masticatory loads using a higher strength framework material, whereas the remainder of the crown/bridge structure is impregnated with a tougher polymer. Using subtractive methods, such as CAD/CAM technology, such intricate internal framework would be difficult to fabricate because there are severe constraints to the angulations that the milling unit can reach in order to create voids and undercuts. This is perhaps the biggest difference between printing and milling — the fact that one allows for
internal geometrical complexity with virtual no limits, whereas milling allows for virtually none (FIGURE 1). The fabrication of lightweight parts\textsuperscript{15,16} with stronger frameworks that better distribute working loads is a trend that has been used in the construction and aerospace engineering fields for nearly half a century (i.e., think of the metallic skeleton of a plane versus the same plane part built out of a monolithic block: which one would be lighter?). Still, these characteristics have yet to find an application in clinical dentistry. 3D printing may enable these advanced systems to be integrated to clinical and/or laboratorial dentistry.

Cost for Variation

In traditional manufacturing, the complexity of the part dictates how difficult it is to fabricate it. Similarly, the more complex the part, the longer it takes to build it; consequently, the cost of fabrication is higher. In short, complexity has traditionally dictated the cost of a certain part, perhaps more so than the price of the raw materials. This is especially true for manual processes of crown, bridge and denture fabrication in the lab, where technician hours are a significant component of the cost. On the other hand, with 3D printing it can be argued that there is virtually no difference for the 3D printer to fabricate a highly complex part or to 3D print a solid block. This effectively means that there is little cost difference to a printed material, regardless of the complexity of the part being fabricated. For some 3D printers (i.e., digital light processing [DLP] printers), it takes the same amount of time to print one layer with 100 parts as it does to print one layer with one part. That is because DLP printers\textsuperscript{1} print one layer at a time by exposing the entire build envelope of a printer to a digital photomask, and there is no difference in exposing the photopolymer to one large area or many small areas. This is further discussed in the 3D Printing Methods section below. Dental laboratories are currently taking advantage of these characteristics to print hundreds of dental crowns at a time (usually overnight) as opposed to having lab technicians fabricating them one by one. The cost per minute of use of a printer ultimately is the same, however, the throughput can be increased by a few orders of magnitude.

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Material Waste

Dental materials have a high cost. Therefore, minimizing waste is highly desirable. During a milling process, a significant percentage of the raw material is wasted.\textsuperscript{6} For instance, a single-unit all-ceramic crown starts as an individual block, and after the milling process is done, the ceramic block is reduced to a fraction of its original size. The milled material is not reutilized, but the cost of the restoration still considers the cost of all of the raw material that was milled. With 3D printing systems, the material waste is reduced drastically. That is because, in most cases, the amount of material needed is only what is required to build the part and its supports. Consequently, the cost associated with material waste that is incurred upon the manufacturer, or the dentist and patient for that matter, is greatly reduced in 3D printing in comparison to subtractive processes.

Scalability

While subtractive systems have been built in a variety of sizes for various applications, the scalability of 3D printing is unique. For instance, 3D parts have been fabricated using photolithography methods down to the nanometer scale for a range of applications,\textsuperscript{17} such as photonics, semiconductors and others.\textsuperscript{18} These have been used to make polymer parts and even high-toughness ceramic coatings on microscale architecture systems.\textsuperscript{19,20} At the same time, 3D printing has been used to fabricate entire rideable cars\textsuperscript{21} or concrete houses that are fabricated in a matter of a few days.\textsuperscript{3} These illustrate the scalability of the technology, from nanometer scale structures of high complexity to massive scale buildings of desirable functionality. The additional advantage of this particular aspect lies in the fact that there are transferable skills and processes that are being simultaneously optimized for various applications, which may ultimately inform the best criteria for fabrication of dental parts. For instance, the ranges of viscosity that are optimal for printing certain polymers in the automotive industry may inform similar processes that use polymers to 3D print dental materials. In other words, this means that all fields, regardless of the scale being studied, may assist in the development and optimization of the technology for various other applications.
Robotic Precision

While many procedures in dentistry remain labor intensive due to the manual character of the protocols, 3D printers, much like CAD/CAM systems, are 100% reliant on the accuracy of robotic instruments. Not only is the precision of these systems invariably improved in comparison to the traditionally manual dental laboratorial methods, but they are also highly repeatable and reproducible. For instance, the ability of prototyping dental parts, inspecting them in a model without worrying about the time and difficulty of repeating long fabrication steps, could be more conducive to better clinical outcomes. In many instances, it is not uncommon for manual processes to result in lightly underperforming results, which end up leading to improvisation and typically a lower quality service. Thus, the ability of being able to quickly replicate a printed part, making the iterations as needed and testing it again until the desirable part is achieved, are aspects that are feasible with 3D printing technology. Moreover, once the desired outcome is achieved, the 3D file is stored in a software, one click away from obtaining the exact same part. These are likely to yield better outcomes for patients and clinicians alike.

Portable Technology

One interesting aspect to note with regard to the rapid expansion of 3D printers is the wide variety of printing systems available in the market. Interestingly, while several industrial printers remain rather large, the far majority of commercially available off-the-shelf printing systems are desktop compatible or sufficiently small to fit in a dental office. In fact, the majority of printers that are designated to the dental market are either small-scale desktop printers or wheeled machines that are comparable in size to a CAD/CAM digital impression/computer system. For instance, printers such as Formlabs’ entire series, 3D Systems’ NextDent 5100 and 1000, Stratasys’ J700 and J720 Dental and Envisiontec’s VIDA and Perfectory series are all desktop units. Therefore, the technology is compatible with other apparatus that are typically kept chairside in a dental office.

Skill Level

Although 3D printers can require a substantial level of engineering and materials expertise, these are typically limited to those interested in understanding or modifying the machine itself and much less so for the ones interested in simply printing. Similar to a regular ink printing in a home or professional office, once a file is sent to the 3D printing unit, one can expect to simply click a button and have the part printed at the end of the process. In fact, recent developments have even removed the requirement for the 3D CAD model to be configured to the specs of the printer of choice because many printing systems are compatible with 3D impression units that can generate a CAD file and submit it directly to the printer of choice. This enables easy and near seamless replication of an existing part by simply copying its external 3D outline and 3D printing. Moreover, the familiarity of the dental clinician with existing subtractive processes makes the transition to a 3D printing process much more user friendly than in other fields.
Fabrication Time

Printing time is a subject of much debate in the field of 3D printing and something that may be considered a significant drawback preventing immediate and widespread implementation of 3D printing technology in the dental office. With existing technologies, 3D printing of a high-resolution dental prosthesis can be time-consuming, and the possibility of doing this chairside as the patient waits seems less than ideal at this point. Having said that, simpler provisional restorations and smaller single-unit crowns can already be 3D printed in as little as 20 minutes or less, with the advantage that the clinician or assistant can be working on other aspects of the treatment as the printer fabricates the restoration. Moreover, a large body of research is being performed on newer methods to reduce printing time for fabrication of various materials. One recent technology was able to reduce the time required to print a complex and relatively sizeable 3D structure from more than three hours to less than 10 minutes, this technology is now commercialized by the company Carbon 3D. Technologies like this are likely to have a major impact in the implementation of 3D printing in dentistry. Recent research has also developed innovative methods to 3D print the outer geometries of a part in its entirety without the need for printing one layer at a time. This is another example that is likely to be useful for printing of simpler objects that can be useful to dental applications.

Technology Compatibility

One advantageous feature of 3D printing technology is that a significant component of the 3D printing market devoted to dentistry relies on the concept of light polymerization of photoactive monomers. This is the case for systems such as Formlabs’ entire series, 3D Systems’ NextDent 5100 and FabPro 1000 and Envisiontec’s VIDA and Perfactory series. As such, the basic principles that guide the field of contemporary restorative dentistry, such as free-radical polymerization, share strong similarities to the driving principles of many 3D printing methods. This means that materials systems that have originally been developed for clinical use and have been extensively characterized are, by and large, compatible with a range of 3D printing systems. This is especially true for polymeric materials and light-/laser-assisted 3D printers.

While the fabrication of a metal-ceramic restoration, for instance, remains far-fetched at the moment, printing of multimaterial polymeric parts is certainly a reality.

Combination of Materials

Multimaterial printing is still a nascent area in 3D printing, and it has been mostly restricted to variations of the same material type. For instance, Stratasys commercializes a printing system called PolyJet, where many photocrosslinkable monomers can be dispensed simultaneously and in a coordinated fashion to fabricate parts with spatially coordinated polymer composition. While the fabrication of a metal-ceramic restoration, for instance, remains far-fetched at the moment, printing of multimaterial polymeric parts is certainly a reality. These have been used to fabricate polymer parts that have self-toughening mechanisms, for instance, by combining very soft, rubbery materials and very rigid photopolymers and guiding the trajectory of cracks through the soft component such that the crack length is increased substantially, thereby increasing the overall toughness of a material (Figure 2). This is a strategy that remains poorly explored in dentistry, but would certainly be leveraged to produce restorative systems with built-in toughening mechanisms that are only possible due to the nature of the printing process. Again, this is an advantage of 3D printing that would never be possible with subtractive technologies.

In summary, the advantages of 3D printing technologies are many and the potential benefits for dentistry are palpable. In the following section, we describe recent examples of printed restorative materials, inclusive of polymer composites and ceramics, which illustrate the potential of 3D printing in the future of dental care.

3D Printing Methods

It is hard to pinpoint exactly how many types of 3D printing systems are available in the market to date. The popularity of 3D printing methods makes the variations of the more common printing types to be developed with surprising speed nowadays. Add to that the fact that printing methods are often developed exclusively for a type of material of interest, and very seldom one can find a 3D printer that can print various types of materials without some modification. For instance, an extrusion 3D printer that dispenses plastics, which is very common, is invariably incapable of performing extrusion of metals or glass using the same mechanisms of dispensing. The same can be said for 3D printers used for tissue fabrication in regenerative medicine in comparison to more common thermoplastic materials. So much so that the field of 3D printing of tissues and organs is more commonly referred to as 3D bioprinting, and in fact it must account for a series of highly complex biological parameters that can
be easily ignored when printing with plastics, metals or ceramics. That is because printing of living cells is far more difficult and specific than printing with inert plastic materials, for obvious reasons. Despite the specificity of each individual printing system described above, one can generally classify 3D printers under three broad categories: extrusion, light/laser polymerization and inkjet. There are a multitude of subtypes to these categories that fall beyond the scope of this review, but generally speaking, 3D printers will fall under one of these categories.

**Extrusion 3D Printing**

In extrusion 3D printing (Figure 3A), typically a thermoplastic polymer, shear-thinning material — either polymeric or not — or a material of adjustable viscosity is loaded to a container that is connected to a print head.28,29 Depending on the mode of polymerization or the characteristics of the material, the print head has to be specific to the mode of delivery of the material. For instance, extrusion of a thermoplastic polymer happens via heating of the print head to a certain temperature; upon dispensing of the molten material, the quick drop in temperature solidifies the printed ink.30 This is the common mode of action of more traditional extrusion desktop 3D printers, also referred to as fused deposition modeling (FDM) 3D printers, which currently dominate the commercial market worldwide. In a different example, when using a preceramic paste, for instance, temperature control may not be as critical because the viscosity of the material or its “shear-thinning” capacity becomes the more important parameter that needs to be regulated such that the material can be squeezed through a needle.28,31–33 Regardless of the print head mechanism, extrusion 3D printers are mounted on some form of X-Y-Z robot, and a computer software coordinates the motion of the tri-axial stage/robot and dispense speed of the printed ink. It is this coordinated motion of these axes with the dispense rate of the ink that allows a material to be printed in 3D in a spatially controlled manner.

**Light/Laser Polymerization**

Different from extrusion 3D printers, light and laser polymerization-based 3D printers (Figure 3B) do not necessarily rely on the X-Y motion of a dispensing robot or the coordinated Z-movement of a print head or a build platform. Instead, in light and laser polymerization-based 3D printers, a photocurable monomer is dispensed onto a vat and either the vat itself moves down while a top-down light/laser raster shines on the surface of the monomer or a build platform moves up as a bottom-up projected light photocrosslinks the material.34–36 This process repeats itself for each layer of a 3D structure, thus giving rise to a 3D part. The more common types of 3D printers that fall under this category are stereolithography printers, where a laser light controlled by a digital mirror travels on the bottom surface of the monomer vat while a build platform travels up, allowing another layer of monomer to seep under the photopolymerized material, thus resulting in the layer-by-layer construction of a 3D part.

Another common type of 3D printer that uses light polymerization is the digital light processing (DLP) 3D printer (i.e., EnvisionTEC’s Perfactory/Vida/EnvisionOne, Autodesk’s Ember, etc.). In this process, printing is obtained by creating a sequence of digital photomasks using a computer software for each layer of a printed part. A common projector shines the light against the bottom surface of a monomer vat and the entire layer is photocrosslinked at the same time in the areas predefined by the digital photomask. As the build platform moves up, a new layer of prepolymer is added underneath the cured part and the final product is built incrementally one layer at a time. There is certainly a range of advantages and disadvantages to each type, and we encourage the reader to refer to review papers on these topics to determine the best use for each application.34,37 It is interesting to note, however, that DLP 3D printers (and variations thereof) have become a more common choice for printing of restorative dental materials, which are the focus of this article, including polymers and ceramics, and it appears that DLP printers may have some advantages for these classes of materials22 given their rapidly expanding popularity. Noteworthy aspects include the greater speed of fabrication of multiple parts and resolution of DLP versus laser-rastering printers.

**Inkjet 3D Printing**

In comparison to extrusion and lithography 3D printing, inkjet 3D printing (Figure 3C) has received less attention with regard to its potential application for restorative treatments. In inkjet printing, the same requirements for the integration of X-Y-Z robots that were described in extrusion printing also exist — meaning, a dispensing robot needs
to dispense the monomer ink in X and Y while either the build platform or the dispenser itself moves in the alternate direction to allow for the incremental layer build-up.\textsuperscript{36,38} One key difference, of course, is that the ink must be of a substantially lower viscosity to permit “jetting” of droplets of the material.\textsuperscript{39–41} This has the potential to make inkjet printing far more accurate because literally one drop of material at a time can be deposited onto a desired substrate. The disadvantage of that, on the other hand, is that printing time can be increased quite drastically, thus making the overall printing time quite slow in comparison to other printing methods.

One key advantage of inkjet systems is that these have been far more advanced in their ability of printing multiple monomers at the same time (i.e., multimaterial printing). This is probably due to the level of advancement that the technology of inkjet printing has accumulated over many years from home office printers. Stratasys, one of the larger manufacturers of 3D printers worldwide, holds the patent for a system called PolyJet.\textsuperscript{42} The PolyJet printer works by dispensing multiple photocrosslinkable monomers of potentially various mechanical properties and colors at the same time. Although these materials have yet to cross the boundaries of simplified monomers that have relatively poor mechanical performance for clinical applications, it is not hard to imagine situations where a multimaterial dental restoration would be printed using a system like this if the correct monomers are tuned to be compatible with the PolyJet system. At this stage, it appears that this falls beyond the commercial scope of the manufacturers of the PolyJet.

### 3D Printed Restoratives — Polymers and Composites

As mentioned at the beginning of this article, although 3D printing has expanded at a tremendous pace as of late and dentistry has been one the fields that has more substantially benefited from the technology, it appears as though the standard perception of most clinicians is that 3D printing of restoratives is not yet clinically feasible, despite recent efforts to review potential applications.\textsuperscript{11} This is despite the fact that commercial printers and printing manufacturers that heavily target the clinical dentistry market have been available for a number of years (i.e., EnvisionTEC, Stratasys, 3D Systems, DWS, Formlabs, NextDent and several others). Perhaps this is due to the fact that printing of restoratives remains far more complex and difficult to attain than other dental products, such as dental models, mouthguards, orthodontic appliances and so on. Similarly, the knowledge required to confidently implement that in a dental practice remains quite specific at this stage. Moreover, despite the fact that the 3D printing industry has been introduced into the clinical dental market, the streamlining of the full digital operation process in the dental clinic has remained less than desirable because the majority of digital scanners do not yet communicate seamlessly with 3D printers; similarly, dental restorative “inks” are not as broadly compatible with various 3D printers as conventional restoratives are, comparatively, “compatible” with any clinician. Secondly, another important reason that explains the slow implementation is the fact that dental materials for restorative applications have fallen under somewhat complex regulatory hurdles by the FDA and other regulatory bodies worldwide.\textsuperscript{43–45} Materials used intraorally (either 3D printed or not) must undergo regulation as a class II device that requires a series of biological testing methods, and it remains unclear how the FDA regulates the process of printing differently from the final printed product (i.e., restorative inks and 3D printers themselves). In other words, there is little variability in the manufacture of a commercial composite material, however, a 3D printable composite ink can have far different outcomes depending on the type of printer that is used and the printing parameters that are set up in the machine, as we and others have demonstrated recently.\textsuperscript{22,46–48} How one may regulate these discrepancies remains a topic of debate,\textsuperscript{41} and it appears that this has halted the implementation of 3D printing in dentistry to a certain extent.

Despite these limitations, 3D printing of polymeric restoratives has been accomplished with relative success in...
the past few years, and that goes beyond the more widespread printing of surgery guides, models, orthodontic appliances and so on, which in this author's opinion are not as critical to the restorative dentist. Readers are encouraged to refer to a recent review paper that describes some basic principles and opportunities of 3D printing of polymeric materials for dentistry. On the commercial side, although various companies have contributed significantly to the introduction of 3D printing in clinical dentistry (i.e., Stratasys, 3D Systems, Formlabs, DWS, Autodesk and many others), EnvisionTEC arguably has established a leadership position on the manufacture of 3D printers for restorative dental applications in the U.S. The company currently has at least four 3D printers that are compatible and engineered for printing of restorative dental materials, including the Envision One cDLM Dental, Vida HD, Vida HD Crown and Bridge and the more advanced Perfactory P4K series. These printers are capable of a printing resolution of up to ~25 µm in X, Y and Z and can reach printing speeds of up to 80 mm/hour, depending on the material. For instance, at maximum speed, according to manufacturer information, a printer would be capable of printing six orthodontic arch models in less than 15 minutes (Envision One cDLM Dental).

Of greater relevance to the context of this article, as with a number of other 3D printing companies (DWS, 3D systems and others), EnvisionTEC currently commercializes a composite resin material called E-Dent 400 MFH, which is a microhybrid resin printing material that is bio-compatible according to a Class IIa determination by the FDA and is approved for 3D printing of crowns and bridges. The material can also be used for the 3D printing of veneers that have a reasonable surface finish as well as denture try-ins. For comparison, per the manufacturers’ websites, the printed E-Dent 400 can reach a flexural strength of approximately 107 MPa, while a conventional Filtek P60 (3M ESPE) composite reaches approximately 160 MPa and a Z100 reaches about 130 MPa. Of interest, the material can also be stained with standard composite staining kits that allow for blending with other shades of restorations and natural teeth.

Another interesting development on the commercial end of printable resins for restorative dentistry is the establishment of manufacturers that, for a long time, were exclusively focused on the commercialization of printable monomers without necessarily commercializing a 3D printer itself. This is the case of the European company NextDent, which currently has a portfolio of 30 biocompatible resins for dental applications, out of which two were developed for provisional crowns and bridges and one for printed dentures, that are indirect restorative materials that the clinician can use as opposed to printable materials that are mostly marketed to lab technicians. As of recent, NextDent has entered the 3D printing market and now commercializes the NextDent 5100 system, which is manufactured in partnership with 3D Systems, one of the larger companies in the field of 3D printing. Similar to EnvisionTEC, NextDent’s crown and bridge resin (NextDent C&B MFH) is also a microfilled hybrid material that reaches a flexural strength of ~107 MPa and, according to the company’s website, is approved for long-term provisional restorations in Europe. It is also worth noting that despite the fact that these commercially available resins are technically only approved for long-term (up to one year) provisional crown and bridge applications, their composition and chemistries are very similar to a variety of composite resins currently available in the dental market. Although the specifics of their composition are not disclosed due to patent protection, these materials are essentially composed of dimethacrylate monomer mixtures with ~50% w/v of inorganic filler in the range of 0.04–0.7 µm in size, which are essentially similar compounds to those used in traditional restorative dental materials already clinically available.

Despite the commercial use of these materials in the dental market, myriad aspects remain largely unknown in the scope of 3D printing of restorative dental materials, which also justifies their slow introduction into the market. Research in this space has also been slower than desirable, and only recently research groups have begun to address the intricacies of the printing process that are likely to determine the usefulness of printed materials in the dental practice. The following section describes some of the research that our group and others have done to elucidate some of the important aspects influencing the properties of 3D printed dental restorative materials.

**FIGURES 4.** Examples of 3D printed dental composites. (Adapted from references 22 and 72.)
One of the first set of research studies addressing the influence of the printing method on the performance of 3D printed resins was the study by the Wismeijer Lab at the Academic Center for Dentistry in Amsterdam,10,46–48 To the best of our knowledge, the first publication from this group in the area of 3D printing of indirect restorative materials for clinical intraoral use came out in 2016. The investigators studied the effects of build direction on the mechanical properties of 3D printed complete-coverage interim dental restorations.49 The authors showed that a 3D printed interim dental material (Temporalis, DWS) had higher compressive strength when printed in a 90-degree orientation than when printed in a 0-degree orientation. The authors proposed that the compression of the sample led to microcracks that expanded from main cracks formed between individual printed layers. This is in line with previous reports that the mechanical properties of printed materials that are anisotropic in nature can be influenced by the printing orientation and that the adhesion between successive layers is weaker than the adhesion within the same layer.11 In a follow-up paper, our group compared the effects of a variety of printing parameters that are preset in a low-cost, commercially available desktop 3D printer (Formlabs+) when used in combination with an unfilled provisional resin (NextDent C&B). We then compared the mechanical performance and degree of conversion obtained using the 3D printed material versus that obtained with standard temporary crown and bridge materials such as Integrity and Jet. Our results showed that samples printed at a 90-degree printing orientation relative to the build platform and using a preset determined for a white resin color resulted in the higher printing accuracy relative to the CAD design.22 Using these parameters, there was no significant influence of number of layers on the mechanical properties of the printed part, different to what Alharbi et al. reported. Moreover, 3D printed samples had comparable peak stress to Integrity and were significantly stronger than Jet, which is a gold standard material for clinical use. On the degree of conversion, 3D printed samples also appeared to have higher and more homogenous polymerization than both Integrity or Jet. These results underline the potential of 3D printed materials to match (and even surpass) the properties (mechanics and degree of conversion) of conventionally cured restorative dental materials. Examples of these 3D printed composites are shown in FIGURES 4.

Overall, these comparisons and research papers highlight some of the fundamental questions that come up when delving deeper into the complexities of 3D printing of intraoral restorative materials. Many aspects of the printing process and how it may influence clinical performance remain unknown. For instance, what are the precise effects (beyond the mechanical ones) when the clinician chooses to print a crown using incremental layers of 10 µm as opposed to 100 µm? This is especially difficult considering that a printed dental crown (or any part) will take longer to be produced depending on the number of layers that need to be created. Moreover, the finish and polish quality of the printed material will increase proportionally with the number of layers that are printed. Similarly, what is the influence of printing orientation in the clinical performance of a printed bridge or crown over the years? Does it matter if a crown is printed at 0 degrees or 90 degrees? One recent publication suggests that these parameters matter quite significantly.47 How much exactly they matter depending on the type of printing (inkjet, extrusion or lithography) remains to be determined. Also, are there postprinting processes that are better to prevent delamination of printed layers or to improve mechanical performance? Is the chemistry of current dental resins, such as photoinitiators and other monomer molecules, optimal for printing systems as much as they are for chairside photopolymerization using the conventional dental curing light? These are questions that are relevant to be addressed if the field of 3D printing in dentistry intends to expand and play a role in the clinical setting like CAD/CAM systems currently do.

An additional thought worth keeping in mind is that current methods of 3D printing and much of the investment that has been put forth in the field have been geared toward processes and methods that are lab-technician friendly and very little in comparison has been targeted to the clinician or 3D printing of intraoral restorative materials. From a clinical standpoint, one may argue that it is more valuable for the dental practitioner to have a chairside 3D printer that can address the aspects of the practice that are currently done manually (i.e., 3D printed restoratives) than 3D printers that can handle laboratorial work (i.e., models, working and study casts, mouthguards and so on). In short, very little of the “3D printing revolution” has directly reached the practice of intraoral restorative dentistry.
Another aspect that is imperative for widespread use of 3D printing in restorative dentistry is that 3D digital impression systems need to be engineered to communicate better with existing 3D printers to allow for a seamless interface between these complementary modalities of digital dentistry. Technically, this is already possible because there are digital impression devices that allow one to save and export STL files that are readable in 3D printers.49,50 Different from CAD/CAM systems that have gone above and beyond in the integration of scanning and building, 3D printers have remained stagnated in their individual niches. More frequently than not, manufacturers either focus on the 3D printing machine, the resin or some combination thereof, and virtually no company has yet come up with a seamless interface between digital scanner, 3D printing system and a set of printable resins, especially for intraoral use in the restorative realm.

3D Printed Restoratives — Ceramics

Perhaps even more than printing of dental composites, 3D printing of dental ceramics for intraoral use has commonly been seen as a distant reality. This is perhaps more understandable than the discrepancies between the general perception and existing market in 3D printing of dental polymers because printing of ceramic materials is not as common and widespread as printing of polymer plastics for the general public. The latter have been highly accessible to the nonspecialized community for many years now and effective printing of high-density ceramics with potential for intraoral clinical application is in its nascent years.51 Having said that, 3D printing of ceramic structures has been used in dentistry for regeneration of bone tissue for a number of years, and the reader is encouraged to refer to other recent reports by our group for an update on that field.5,52–55

Despite the use of a variety of 3D printing techniques to fabricate ceramic-based scaffold materials for craniofacial regeneration, printing of dental ceramics for restorative applications has received little attention and most of the published works date back to only a few years ago.56 This is because printing of ceramics has traditionally been done with the use of preceramic pastes or slurries, which generally cannot reach the level of density that usual dental ceramics have to result in desirable load-bearing mechanical properties for intraoral dental use. In order for preceramic materials to be extrudable or printable using traditional 3D printing methods, they need to have a relatively low viscosity (or be shear thinning) and include a variety of binders and other additives to permit fine-tuning of the presetting properties that make the material moldable or extrudable. Early work from Lewis et al.57,58 paved the way for more substantial contributions on 3D printing of ceramic materials, which more recently have been reported by Smay et al.59 These groups, however, focused primarily on the “direct writing,” or extrusion 3D printing, of colloidal ceramic materials that solidify to reach higher properties upon sintering, and it was not until the establishment of far more advanced ceramic printing technologies that printing of high-density and high-strength dental ceramics began to take form. Table 1 summarizes recent developments in the 3D printing industry that are applied to ceramic printing, which are also illustrated in Figure 5. And although only a fraction of these systems are compatible with high-strength dental ceramics 3D printing, the summary

### Table 1

<table>
<thead>
<tr>
<th>Ceramic 3D Printers and Specifications (Adapted from reference 60.)</th>
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<tr>
<td><strong>3D printer</strong></td>
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<tr>
<td>3D Systems ProX DMP 200 Dental</td>
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<tr>
<td>3d-figo FFD 150H</td>
</tr>
<tr>
<td>3DCeram Ceramaker</td>
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<td>Admatec ADMAFLEX 130</td>
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<td>AIM3D ExAM 255</td>
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<td>DDM Systems LAMP</td>
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<td>ExOne Innovent</td>
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<td>HP Jet Fusion 3D 4210</td>
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<td>Kwambio Ceramo One</td>
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<td>Lithoz CeraFab 7500</td>
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<td>nScrypt 3Dn 450HP</td>
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<tr>
<td>Prodways ProMaker V6000</td>
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<tr>
<td>Voxeljet VX4000</td>
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<td>XJet Carmel 1400</td>
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illustrates the breadth of machines and methods available in the market.

Polymer-derived ceramics, a class of printable ceramics introduced in recent years, are photocrosslinkable materials that upon heating (typically under inert atmosphere) can pyrolyze into more stable and rigid ceramic structures. Recent work has demonstrated that by attaching thiol, vinyl, acrylate, methacrylate or epoxy groups to an inorganic backbone, such as a siloxane, silazane or carbosilane, these preceramic monomers can be photocrosslinked with standard UV light and fabricated with highly intricate shapes. This allows for straightforward stereolithography printing of preceramic monomers with virtually any size and a very high printing resolution. For instance, a UV-curable siloxane resin was formulated with methylsiloxane and vinylmethoxysiloxane and 3D printed using a Formlabs Form 1+ 3D printer. Pyrolysis at 1,000 degrees Celsius in argon formed fully dense intricate ceramic parts, with no porosity or surface cracks observed by scanning electron microscopy and transmission electron microscope (TEM). This was, as one would expect, accompanied by 42% mass loss and 30% linear shrinkage. Still, the mechanical properties of these preceramic monomers are below par in comparison to traditional dental ceramic materials. While these ceramics are relatively weak in the context of dental restorations, they paved the way for more advanced printing of high-strength ceramics with properties that are more adequate for introral use, such as those obtained via a lithography-based ceramic manufacturing (LCM) method.

In fact, perhaps the most relevant introduction into the dental market has been the development of the LCM technology, which simply modifies existing methods of DLP 3D printing to make it compatible with printing of a high-density ceramic slurry mixed with a binder and photoactive monomers. Although not much information is available on the precise mechanisms of action of LCM-based 3D printing, the system generally operates as a standard DLP 3D printer and the key difference is in the material composition. The ink is composed of a mixture of ceramic microparticles (~60%) in a photocrosslinkable matrix, which sets upon exposure to the projected light. After printing, the 3D printed “green” ceramic-monomer mixture undergoes a process of cleaning and debinding, upon which the polymer is removed without affecting the stability of the preceramic structure. Upon sintering, an average 25% of linear shrinkage occurs, and the ceramic particles fuse to result in a high-density (> 90%) ceramic part that can be fabricated at virtually any geometry, with a maximum resolution of about 25 µm. The method is theoretically compatible with any type of ceramic material. The mechanical properties of these parts are excellent and reach flexural strength values that are as high as 430 MPa, which closely approximate the flexural strength of some dental alumina ceramics, for instance. This method was originally developed at the Vienna University of Technology, and high-density (97%–99%) zirconia and alumina structures with Vickers hardness of as high as 17.5 GPa (as rigid as dentin) have been produced. The LCM technology is currently owned and commercialized by Lithoz GmbH, a spin-off company from the lab that developed the method, and our team has done considerable work in collaboration with Lithoz to test the mechanics of a variety of high-density alumina samples 3D printed by LCM. We have also replicated some of the microarchitectural complexities of dental enamel in the form of printed ceramics, which we hope will form the basis for the next generation of “bioinspired” dental ceramic crowns and bridges with the same durability, strength and toughness as the native dental enamel. Lithoz has also partnered with large ceramic companies in Europe, and in principle, 3D printers that are capable of fabricating high-resolution, high-density and high-strength dental ceramics are already available to be purchased for clinical/lab use (regulatory concerns notwithstanding). The feature resolution generated using LCM has been reported to reach 25 µm and several examples of complex structures have been reported.
including honeycomb catalyst supports, heat exchangers and negative Poisson’s ratio metamaterials and a wide variety of other examples. TABLE 2 compares 3D printing processes that have been utilized for fabrication of ceramic structures in various resolutions and for various applications.

**Conclusion**

In summary, the expansion of 3D printing in the restorative world is tangible. The scenario where a patient will walk into a dental office and order a 3D printed crown is no longer restricted to science fiction and examples of that are already occurring in small numbers worldwide. Much research remains to be performed to determine the critical aspects that are intrinsic to 3D printing of restorative dental materials, but the field is evolving at rapid speed. Nevertheless, only time will determine the successes and failures of the field and judge the true advantages of 3D printing over existing technologies that have been tested and proved to work effectively in the dental practice, like traditional CAD/CAM technology. On the comparisons of subtractive versus additive manufacturing for existing restorative materials, there is no question that subtractive is still a far more advanced technology. However, for the early adopter and those willing to shape the future of dental care, there is certainly room for investment in 3D printing technology. Many new developments are warranted to come in the near future and directly affect the field of restorative dentistry.

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Applications of 3D Printing in Craniofacial Surgery

Maxime M. Wang, BA; Amel Ibrahim, MD, PhD; Lukasz Witek, PhD; Paulo G. Coelho, DDS, PhD; and Roberto L. Flores, MD

ABSTRACT Plastic surgery has seen an increased adoption of 3D printing technology in all steps of the reconstructive process. From sterilizable intraoperative 3D printed models to live bioprinting, 3D printing is helping surgeons refine existing treatment approaches, driving innovation in areas such as tissue engineering and vascularized composite allotransplantation. As surgeons identify clinical need, 3D printing applications to plastic and craniofacial reconstruction will only continue to evolve.

AUTHORS

Maxime M. Wang, BA, is a medical student at the NYU School of Medicine and a research fellow at the Hansjörg Wyss Department of Plastic Surgery at the NYU Langone Medical Center in New York. Conflict of Interest Disclosure: None reported.

Amel Ibrahim, MD, PhD, is the director of the human stem cell research program in the department of biomaterials and biomimetics at the NYU College of Dentistry, the Hansjörg Wyss Department of Plastic Surgery and the NYU Langone Medical Center in New York. She is a member of the Royal College of Surgeons. Conflict of Interest Disclosure: None reported.

Lukasz Witek, PhD, is an assistant professor in the department of biomaterials and biomimetics at the NYU College of Dentistry in New York. Conflict of Interest Disclosure: None reported.

Paulo G. Coelho, DDS, PhD, is the Leonard I. Linkow professor of biomaterials (dentistry), plastic and reconstructive surgery (medicine) and mechanical and aerospace engineering (engineering) at New York University. Conflict of Interest Disclosure: None reported.

Roberto L. Flores, MD, is the Joseph McCarthy associate professor of reconstructive plastic surgery at the Hansjörg Wyss Department of Plastic Surgery and the director of the cleft lip and palate program at the NYU Langone Medical Center in New York. Conflict of Interest Disclosure: None reported.

The classic principles of plastic surgery practice mandate the restoration of form and function by balancing aesthetic and physiological demands while limiting morbidity. Plastic surgeons routinely operate on all parts of the body, with virtually no anatomic barriers, and therefore often collaborate with a broad array of medical, surgical and dental specialists. While each anatomical domain has its own set of considerations, a common plastic surgery principle is the replacement of “like with like.” In other words, the use of autogenous tissue with similar histologic and mechanical properties is often preferable to prosthetic replacement and is a guiding principle to reconstructive and aesthetic surgery. In craniofacial reconstruction, for example, autogenous tissue is commonly preferable in the restoration of deformities caused by congenital, oncolgic, traumatic and iatrogenic insults. Still, there remain limitations to the gold standard of autogenous reconstruction.
including size, shape and stock of donor tissue and increased length of the operation as well as donor-site morbidity. These challenges, however, present an opportunity for innovative approaches to craniofacial reconstruction, such as the application for additive manufacturing or 3D printing. The benefits of 3D printing technology to the field of plastic surgery include the manufacture of customized patient models, surgical templates and cutting guides, personalized implants and tissue engineering scaffolds.

3D Printing

3D printing is the process by which two-dimensional (2D) forms are sequentially deposited or fused in layer-by-layer fashion to produce a 3D product. To begin the process, a computer-aided design (CAD) model is digitally created using data from sources including photographic, computed tomography (CT) and magnetic resonance imaging (MRI) images or by using 3D rendering software.

Once the digital CAD model is finalized, it is segmented into a set of digital slices that are then exported to a readable file, exported to a compatible 3D printer and printed into the final physical model. The printer deposits or fuses successive layers composed of liquid, polymer or colloidal gel material to construct the final object. Layer dimensions vary based on printing technique, printer resolution and printing material.

3D printing technologies are currently categorized into four platforms (TABLE).

Fused deposition modeling (FDM):1,2 FDM is an extrusion-based 3D printing system. Objects are printed using a thermoplastic polymer dispensed from a spool through a heated extrusion nozzle and deposited onto a build platform. Most polymers solidify immediately upon deposition on the build platform. This method allows for printing in multiple colors and is commonly used to print dental models or facial prostheses patterns.

Stereolithography (SLA):3 Originally introduced in the early 1980s, SLA is often referred to as the first rapid prototyping processing technology.4 In SLA, a build platform is submerged in a vat of photocurable resin. With exposure to a concentrated ultraviolet light beam, layers of this curable resin are polymerized and solidified in a predetermined CAD pattern. Subsequent layers are printed as the platform is raised by microns at a time from the resin.

Selective laser sintering (SLS):5,6 Similar to photopolymerization-based 3D printing, SLS utilizes a high-powered CO2 laser to fuse or sinter layers of particles. The laser scans the material — commonly ceramics — in a preset pattern, heating it to its material melting point, resulting in selective sintering in a layer-by-layer fashion to build the 3D form.

3D plotting/direct ink writing (DIW)/robotic assisted deposition/robocasting:7–9 DIW-based 3D printing, commonly referred to as robocasting, utilizes a computer-controlled microprinter equipped with a syringe gantry. DIW allows for the assembly of a synthetic structure, commonly composed of ceramic-based material, in a layer-by-layer fashion.10 DIW allows for printing of a precisely tailored lattice structure with defined parameters. DIW customized modifications can be systematically incorporated on the macro-, meso-, micro- and nanometer levels to allow printing of an array of materials at room temperature with minimal post processing.11,12 Due to its versatility in printing materials and high level of construct design customizability, DIW has shown increasing adoption for printing of tissue engineering constructs (FIGURE 1).12,13

### TABLE

<table>
<thead>
<tr>
<th>Technique</th>
<th>Pros</th>
<th>Cons</th>
<th>Material</th>
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<tbody>
<tr>
<td>Fused deposition modeling (FDM)</td>
<td>No need for secondary support structure.</td>
<td>Heat-driven extrusion process.</td>
<td>Thermoplastic polymers</td>
</tr>
<tr>
<td>Stereolithography (SLA)</td>
<td>Complex features can be incorporated.</td>
<td>Only applicable for use with photo-polymeric resins.</td>
<td>Poly (propylene fumarate) (PPF)</td>
</tr>
<tr>
<td>Selective laser sintering (SLS)</td>
<td>Support structure is not required.</td>
<td>Requires a high-powered laser to fuse particles together.</td>
<td>Various powder form materials (nano-HA, carbonated HA, β-TCP)</td>
</tr>
<tr>
<td>3D plotting/direct ink writing (DIW)/robotic assisted deposition/robocasting</td>
<td>Fabrication feasible at room temperature; capable of bioplotting. Higher resolution (50 µm–1,000 µm). Multiple materials may be printed/codeposited.</td>
<td>Commonly associated with a sintering step when working with ceramics.</td>
<td>Biomolecules Cells Bioactive ceramics (HA, β-TCP) Bioactive glasses</td>
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Limited access to resources and high cost were previously prohibitive in the dissemination of this technology, but recent advances in 3D printing technology have made it more widely available. In particular, the decreasing cost of 3D printers combined with the increasing array of hardware options has resulted in a growing adoption and implementation of 3D printing in both academic and commercial settings. Plastic surgery has witnessed the advent of 3D printing across the reconstructive process, from surgical planning templates to implantable biomaterials and regenerative technologies. Many surgeons are integrating 3D printing into their workflow as commercial and in-house systems of 3D manufacturing harness computer-aided design and manufacturing (CAD/CAM) technology, which is able to visualize the relationships between points and surfaces in 3D, which is particularly advantageous in a craniofacial context where more complicated relationships exist compared to other anatomical areas of reconstruction. Furthermore, bony surgery can be performed on craniofacial skeletal models, effectively simulating critical parts of the procedure. The opportunity to simulate the procedure provides a critical advantage to surgical preparation and planning in cases where the patient’s condition is rare, the anatomical defect is complex or the surgical approach is unique/customized.

Commercially available, custom 3D printed patient models are being used in patient consultation and reconstructive planning in cosmetic surgery, particularly in rhinoplasty. In these systems, CT and photographic images of the patient are used to print preoperative and planned postoperative 3D models of patients’ faces and are used to discuss goals and explain reconstructive options. Klosterman and Romo reported that use of these 3D printed models in patient consultations resulted in positive patient ratings and generated requests to use models in future consultations. The use of these models has been described in primary and secondary rhinoplasty (FIGURE 3).

Models can be printed to assist surgeons in preoperative preparation for the reconstruction of rare craniofacial conditions or anatomically complex areas. Engel et al. described the printing of a skull model of a patient with hypertelorism in order to optimize surgical approach and reduce surgery time. These models offer substrate for practice and planning not available with cadavers as congenital conditions are commonly treated at the pediatric age and congenital facial deformities are rarely present in a cadaver. Longfeld et al. 3D printed a temporal bone training model that was used to train surgeons through preoperative simulation.

Additionally, 3D printed, patient-specific models can be sterilized and brought to the operative field to serve as intraoperative guides when reconstructing complex 3D geometries. These models can be particularly advantageous in uncommonly performed reconstructions or procedures requiring exact 3D precision. Although 3D printed models are commercially available from third-party vendors, in-house manufacture of patient-specific models using preoperative scans can further streamline the processes. Rather than using commercial services, in-house design and fabrication can lead to reduced costs and permit greater control by the surgeon on the design and precision of their reconstruction. Flores et al. described an in-house technique for design and fabrication of models for ear reconstruction and rhinoplasty (FIGURE 4).
The use of patient-specific models is not limited to soft tissue reconstruction; sterilized stereolithographic models have been used to fit operative hardware such as titanium plates. Plates can be prebent and custom molded to the patient for reconstruction during routine and complex craniofacial trauma, significantly reducing operative time and increasing operative precision.23–25 These models can be constructed using mirror-image duplication of the contralateral, unaffected side, providing a target bony form to which a titanium plate can be molded. In more complex reconstructions of large or composite defects such as free-fibula flap reconstruction, CAD/CAM has been used to design osteotomies, and 3D models are printed, sterilized and used to prebend fixation plates prior to harvesting of the flap to decrease ischemia time.26 Particularly, this technology may be useful when the original architecture of the mandible has been altered or destroyed.27 The use of models for accurately bending fixation plates has also been applied in cranial28 and orbital wall reconstruction.29–31

**Surgical Templates and Guides**

**Maxillary and Mandibular Reconstruction**

3D modeling and printing have allowed for major advances in microvascular free-flap reconstruction, particularly of the upper and lower jaw. One of the more sophisticated applications of this technology to jaw reconstruction involves the microvascular reconstruction of the mandible/maxilla with concurrent placement of osteointegrated implants and prosthetics, restoring occlusion and providing full oral restoration in a single intervention or Jaw in a Day (3D Systems, Rock Hill, S.C.).32 Ordinarily, the time between bony and soft tissue microvascular reconstruction of the jaw and full dental restoration can take several months or even years.32 Levine et al. published their protocol for Jaw in a Day, whereby they describe the use of virtual surgical planning (VSP) in order to design and prefabricate patient-specific cutting guides to allow for the precise and expeditious harvesting and repositioning of a fibular-free flap for mandibular reconstruction. The authors note that 3D technology facilitates the shaping of the fibula to allow for a one-stage, patient-specific reconstruction. In these cases, positioning is crucial because misplacement within the occlusal plane might result in an inability to use the reconstructed bone for fixation of the prostheses. Additionally, by preoperatively designing cutting guides that determine the angle of osteotomies that create pieces that resemble the desired reconstruction, this technique minimizes ischemia time of the harvested flap. Finally, guides are fabricated for precise placement of osteointegrated implants directly into the fibula flap prior to inset onto the face, such that a dental prosthesis can then be placed immediately after surgery, a service that would not be feasible using traditional reconstructive techniques. The authors attribute their development of this method to the clinical demand of successfully completing increasingly complex head and neck surgery while limiting patient morbidity and the time to full-functional restoration. This method has been adopted by other large academic centers and has likewise been applied to reconstruction of large neoplastic resections of the edentulous mandible and to reconstruction of the maxilla.32–36 Through this technique, the authors cited the ability to better restore form and function of the jaw by optimizing angle
and positioning with an overall decreased number of final procedures and cost reduction. They note that the procedure is not without disadvantages, stating that there may be a steep learning curve to the design, implementation and effectiveness of 3D printing technology. Additionally, loss of the fibular flap may result in loss of dental implants and prostheses, though long-term rates of implant survival have yet to be assessed. As such, long-term studies regarding the survival of jaw in a Day dental implants remain necessary.55

Cranial Reconstruction

3D cutting guides have also been applied in cranial reconstruction. Dorafshar et al. published their experience using 3D printed guides for cranial reconstruction in patients with metopic, unicoronal and multisutural synostosis.57 Their group described the application of VSP and 3D printed guides for cranial cuts in a patient with late-presenting scaphocephaly58 as well as multisuture and revision craniosynostosis.59 They propose that because of their center’s experience and familiarity with VSP-CAD/CAM applications, use of 3D printing technology could improve operative results and may be indicated in complicated cases including revision craniosynostosis, facial bipartition, four-wall box osteotomy, reduction cranioplasty and distraction osteogenesis.40 Proponents of VSP-CAD/CAM note favorable safety41 and cost profiles resulting from decreased operative time42 due to the precision of pretemplated osteotomies, however, these studies are pending and it is certainly possible that dependence on this technology may, in fact, increase the cost of care for certain procedures. Therefore, it is critical to demonstrate a measurable benefit to patient outcomes or cost of care in order to justify the use of this technology.

Orthognathic Surgery

VSP-CAD/CAM and 3D printing have seen adoption in orthognathic surgery as well and have become commonly available through commercial vendors. Polley and Figueroa published their experience with an intraoperative positioning system that combines CAD/CAM-designed drilling guides, detachable occlusal guides and occlusal splints.44 These cutting guides may be of particular benefit, but are not limited to use in orthognathic procedures involving complex movements of the jaws or in patients with severe facial scoliosis in which the ideal midline is not easily realized. As discussed with other forms of craniomaxillofacial surgery, investigation in this area suggests that preoperative evaluation of dental occlusion with VSP-CAD/CAM results in more accurate correction compared to conventional methods, decreased operating time, saved costs and favorable safety profile.42–44

In orthognathic surgery, VSP and CAD/CAM have also been used to preoperatively design and 3D print custom, patient-specific occlusal splints.44 Schneider et al. conducted retrospective randomized controlled trials of VSP-designed, 3D printed splints that demonstrated less required intraoperative modification of splints to achieve desired occlusion, decreased operating times while resulting in high-fidelity, postoperative orthognathic outcomes compared to conventional methods.45 Given that conventional methods require multiple steps that may amplify errors in the creation of intraoral splints, there remains interest in the development of in-house protocols for splint design and manufacture via 3D printing.46

Vascularized Composite Tissue Allotransplantation

The application of VSP in craniofacial vascularized composite tissue allotransplantation (VCA) illustrates its ability to facilitate the planning and execution of high-complexity, high-precision, multidimensional procedures. In addition to conventional 3D CT craniofacial skeletal and vascular evaluation commonly employed in VCA, VSP has been used to design and translate planned osteotomies via the printing of customized donor cutting guides (Figures 4). In bimaxillary facial transplantation, lack of conventional landmarks may interfere with the ability of a surgical team to orthotopically attach the transplanted facial structure onto the cranial base. Dorafshar and Rodriguez et al. demonstrated in a
sentinel case series that VSP could be used to plan and produce cutting guides to perform full-facial osteomyocutaneous transplantation (based on the LeFort III segment) with six rotational axes in a series of five cadaveric cases and one clinical case. The authors reported good to excellent outcomes in five of the six degrees of freedom. In a multistep, multiteam procedure, the authors reported successful translation of virtually planned osteotomies to end product. While the authors acknowledge the challenges of timing computer reconstruction with regard to suddenly available donors in a trauma setting, they and other authors advocate for the usefulness of VSP and 3D printing in VCA, especially in cases of known, stable recipients. Overall, in the rapidly evolving VCA landscape, there has been increasing implementation of VSP and CAD/CAM technology. However, the ability of current CAD/CAM-generated guides may be limited in their ability to account for dynamic movement of a multisegment, composite tissue structure. Outcomes related to the influence of soft tissue and muscles of mastication on allograft function, for example, have not been evaluated and the utility of CAD/CAM in VCA continues to be an active area of development.

Patient-Specific Implants

Orthognathic Surgery

Conventional methods of surgical planning and intraoperative fixation in orthognathic surgery require manual bending of titanium plates to rigidly fix the maxilla in its new 3D position and rotation. Following orthognathic surgery, preoperative and postoperative orthodontics are commonly employed and may further be required to correct imperfections in occlusion secondary to relapse or suboptimal restoration of dental relationships. 3D imaging, planning and prototyping technology is evolving such that concurrent to the development of the 3D printed strategies described above, there has been rapid development of patient-specific implants (PSI) that may obviate the need for splint placement or prebending of titanium plates based on models. Fabricating PSI via additive manufacturing can result in accurate translation, rotation and fixation of the maxilla that do not require the use of wafers or splints. Adoption of 3D printed cutting guides and PSI have not been widely adopted as of yet, but reports underscore the viability, compatibility and time-saving potential of VSP-CAD/CAM systems in creating cutting guides and PSIs with favorable mechanical properties without increased risk for infection that may reduce the need for pre- and postoperative orthodontic treatment.

Orbital Wall Reconstruction

The ability to customize implants to complex geometries based on CT data has made 3D printing of PSIs particularly suited to orbital wall reconstruction. In the orbit, a change in orbital volume resulting from an imprecise orbital wall reconstruction can significantly affect the position of the globe and secondary ocular function. Stoor et al. described a protocol for the design and placement of titanium mesh PSI designed with CAD/CAM by mirroring the intact maxilla and orbit. Using mirror-imaged and age-matched control scans, PSIs can be designed to have a high surface contact area with intact orbital bone to ensure optimal positioning and stability of the implant. The development of increasingly robust, safe, accurate orbital wall PSIs continues to be an active area of development, however, because of the delicate nature of orbital wall reconstruction compared to conventional scan resolution, small inaccuracies can be amplified in the CAD/CAM process.

Cranial Reconstruction

The benefit of 3D printed PSIs in cranial reconstruction can be readily appreciated given the limitations of autogenous reconstruction and conventional reconstructive implants of the calvarium. Limited size and stock of donor bone and decreasing osteogenic capacity of the dura after 12–18 months, particularly across critically sized defects, can present challenges to successful cranial reconstruction.
Dean et al. presented a protocol that utilizes additive manufacturing in order to print custom, sterilizable plates that can be used in cranial reconstruction. They found that 3D printed implants were less expensive and better fitting, thus more likely to protect the brain from trauma and infection and more cosmetically suitable compared to manually generated skull plates.

Likewise, Gordon et al. presented their experience performing single-stage cranioplasty for benign and malignant skull neoplasms using 3D printed, patient-specific implants. The authors reported no implant-related complications at one to 16 months and ideal long-term aesthetic results, with quantitative analysis showing correction of soft tissue defects. Further, these cranial implants have been successfully modified to integrate a built-in hydrocephalus shunt valve device in human patients.

3D Printing and Tissue Engineering

3D Printed Biomaterials

The ideal bioregenerative construct should be biocompatible, facilitate tissue regeneration, have favorable degradation kinetics and eventually be replaced by vascularized, uninterrupted native tissue. 3D printing technology has a potentially unique role in the field of tissue engineering as the macro-, meso, micro- and nanoarchitecture of scaffolds can be tailored to optimize osteoconduction, vascularization and absorption. Furthermore, 3D printed osteoinductive constructs can be customized to fit and fill any size or shaped defect, providing an ideal pathway to personalized hard tissue replacement constructs. The significance of potentially regenerating bone and cartilage in the face and skull cannot be overstated. Autogenous sources are limited by donor site morbidity, limited tissue stock and shape, incomplete graft take, prolonged operative time and extended hospital stay. Prosthetic replacements are challenged by infection, fracture, exposure and the morbidity of extrication and replacement. In craniofacial reconstruction, the combination of scaffold support constructs, osteogenic factors and stem cell therapies are popular novel avenues of investigation in this rapidly evolving landscape. By combining CAD/CAM strategies and biomaterial engineering, well-characterized materials such as beta-tricalcium phosphate (β-TCP) can be geometrically optimized to achieve ideal regenerative capacity, degradation profiles and macrogeometry, customizable to any defect shape or size.

These customizable 3D printed scaffold constructs have been investigated in a variety of contexts including craniofacial reconstruction and stand to address many of the limitations associated with conventional reconstructive strategies. Adult large animal models have demonstrated that these scaffolds can regenerate bone across even critically sized craniomaxillofacial defects of the cranium, mandible and maxilla. In contrast to unfilled defects, these 3D printed scaffolds have been shown to regenerate bone across critically sized craniotomies and surgically created clefts with evidence of maturing lamellar morphology and vascularization of newly formed bone.

Optimization studies have delineated ideal ratio of pore to strut size of lattice structures in order to facilitate osteoconduction and osteoinduction of native osteoprogenitor cells. This lattice-based scaffold design further allows for scaffolds to be used as carriers for osteoinductive pharmacologic agents, which further promote differentiation and proliferation of regenerated bone. Short-term studies of these scaffolds additionally suggest that 100% β-TCP scaffolds undergo improved remodeling and resorption in vivo, suggesting favorable degradation of these constructs. Meanwhile, these scaffolds have been shown to be safe in animal models, without scaffold fragmentation, ectopic bone growth or negative impact on craniofacial sutures. 3D printing technologies have also been shown to effectively regenerate cranial bone in immature animal models, notably without disruption of growing cranial sutures. Pediatric craniofacial reconstruction is a particularly challenging area of investigation, as pediatric patients tend to have more limited donor-bone stock and shape. Additionally, the growth and development of the pediatric skeleton traditionally requires multiple operations, especially when xenografts are used. Degradable β-TCP scaffolds have the potential to address this important need, though thus far investigation in animals has been limited.
3D printing technology has also been applied in efforts to generate anatomic cartilage tissue. One area of investigation is in temporomandibular joint (TMJ) disc reconstruction in the treatment of TMJ disc thinning or following discectomy for severe TMJ disease. Like in other areas of tissue engineering, investigation of TMJ disc regeneration has incorporated construction of various flexible scaffold components with cell therapies. 3D printers have been used to print scaffolds to more closely approximate TMJ disc fibrocartilage microstructure and hence better reproduce mechanical properties of tissue engineered discs. Investigation in this area remains preliminary, however, and groups have investigated different extracellular matrix formulations, scaffold cell-seeding methods, 3D delivery of growth factors and scaffold-free self-assembling discs.

**Bioprinting**

Additive fabrication of cellular, biointegratable live tissue is another active area of investigation and represents some of the most sophisticated applications of 3D printing. Ideally, bioprinting of human cells suspended in a biodegradable matrix would produce a tissue construct that could be implanted, vascularized and incorporated with minimal donor site morbidity and no permanent alloplastic implants.

The practice of bioprinting is complicated and the critical steps of the process are under active refinement. Stem cells are first harvested from the patient and expanded in vitro. The cells are suspended in a hydrogel matrix and printed into a scaffold containing the appropriate cell signaling agents and placed into a bioreactor, an incubator that provides the stem cell the necessary oxygen and nutrients to differentiate and proliferate. The scaffold with the now differentiated, mature and expanded cells are implanted into the patient.

Cartilage bioprinting has been investigated in total auricular reconstruction, where conventional reconstruction using a costal cartilage framework is technically demanding, spatially complex and requires multiple operations, often with less than ideal restoration of form and function. Soft tissue scaffold-based tissue engineering continues to be challenging secondary to contracture or necrosis of poorly vascularized cartilage and soft tissue.

Protocols have been proposed for 3D printing of cartilage that use hydrogel-(cellulose or agar) based scaffolds that give the structural foundation for seeding of chondrocyte or adipocyte precursor cells. Initial reports demonstrate good ability of 3D printing to generate constructs in complex 3D configurations that ultimately allow for proliferation of human cells. However, the technology remains in early development, with no current optimized protocol for the combination of scaffold design, production and chondrocyte induction yet established. Furthermore, the mechanical integrity of the scaffolds and generated cartilage is an area of active development as many cartilage constructs undergo contracture and see progressively structural deformity over time.

Bioprinting of bone tissue has also seen advancement in recent years. Like cartilage bioprinting, bone bioprinting combines hydrogel-based matrices with bone-marrow derived mesenchymal cells and has shown promise in fabricating mechanically stable 3D printed constructs with viable bone-precursor cells. The matrix as well as cellular components of this strategy continue to be refined. For example, Fischer et al. investigated the combination of collagen I with agarose hydrogels in order to improve the mechanical stiffness and printing contours of their printed constructs. Furthermore, they report that the addition of collagen induced changes in cell morphology and enhanced osteogenic differentiation.
Summary/Discussion

This review has described the ways in which 3D printing technology has been incorporated into several aspects of plastic surgery reconstruction. From patient-centered models to intraoperative templates to CAD/CAM cutting guides, implants and tissue engineering constructs, 3D printing technology has demonstrated an overall ability to accurately translate 3D imaging data into customizable tools that can be leveraged by surgeons.

Across these various applications, 3D printing stands to be a less labor-intensive, streamlined and high-fidelity solution to complex 3D visualization and reconstruction. By addressing 3D planning preoperatively, 3D printing has been shown to decrease OR times, which ultimately can result in significant cost reduction. VSP has been demonstrated to produce more predictable outcomes compared to conventional planning methods in orthognathic surgery and has begun to be a de facto part of VCA protocols and other challenging reconstructions due to its ability to account for multiple spatial and anatomical variables and facilitate intersurgeon communication to ultimately reduce pre- and postplanning variability. 3D printing is becoming increasingly available in a commercial setting, and the ability to design custom implants and reconstructive solutions is shaping the demands and approaches of industry and academic leaders alike. Lastly, CAD/CAM and 3D printing are integral parts of novel tissue engineering strategies, as they make it possible to custom design constructs tailored to a specific patient's needs.

As 3D printing becomes more widely adopted, important regulatory and safety questions will need to be addressed.50 To that end, more high-quality studies that directly compare 3D printed approaches to conventional methods are necessary.

Future directions for 3D printed technologies include development and refinement of both computer aided design and manufacturing. While at present most commonly used VSP systems take into account one or two tissue systems (bone, vascular or soft tissue) in isolation, combined tissue modeling and printing that takes into account dynamic interactions of muscle, soft tissue and bone46,50 or incorporates multifunctional printed technology51 will prove crucial for increasingly sophisticated reconstructions, made possible as 3D printing technology evolves. Furthermore, 3D printing technology itself continues to rapidly evolve—development of in situ or intraoperative bioprinting directly into surgical fields as well as other novel permutations of 3D printing will continue to broaden our surgical reconstructive horizons.92 Surgeons stand to overcome longstanding obstacles in craniofacial plastic surgery as they continue to adopt, evaluate and improve the possibilities of 3D printing technology.

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**LOS ANGELES COUNTY**


**CENRTURY CITY** — GP in 11 story prof med bldg. Has 5 eq in a 1,955 sq ft. Grossed approx. $715K. Buyer’s net of $184K. Property ID #5209.

**CERRITOS** — Located in a busy strip mall, this GP has almost 50 yrs of goodwill. Consists of 6 eq ops. Property ID #5286.


**CULVER CITY** — GP w/ 60 yrs of goodwill to offers is located in 2 story free standing bldg. Grossed $658K in 2018. NET $260K. Property # 5258.


**LADERA RANCHO** — Beautiful GP in premier shopping center. Has 4 eq operators. Grossed approx. $1.9M in 2018. NET $400K. Property ID #5262.

**LAGUNA NIGUEL** — Coming Soon!

**LYNWOOD** — GP w/ 35 yrs in a 1 story free standing bldg. Grossed approx. $325K in 2018. ID # 5274.


**ROWLAND HEIGHTS** — Established GP with over 8 years of goodwill. This modern designed practice has 8 eq operatories. On a approx. 1,815 sq ft suite. PPO and Cash Only. Grossed approx. $560K in 2018. Property # 5274.

**SAN DIEGO COUNTY**

**CARLSBAD** — This beautiful practice has over 22 yrs of goodwill. Has 4 eq ops in a 1,800 sq ft suite. Fee for service office. Grossed approx. $440K for 2018. Property ID # 5256.

**CARMEL VALLEY** — Price Reduced! Turn key practice has 3 eq ops and 1 plumbed not eq on an approx. 1,815 sq ft suite. PPO and Cash only. Grossed approx. $325K in 2018. ID # 5274.

**CHULA VISTA (Turn-Key)** — Well laid out practice in a 2 story med/dent building. Has 3 eq operatories and 1 plumbed not eq. On a approx. 1,400 sq ft suite. Grossed approximately $588K in 2018. Great potential for a full time dentist. Property ID #5273.

**EL CAJON** — GP w/ Real State. Consists of 5 eq ops and equipped with 3D Sirona CBCT Digital X-ray. Grossed over $1M in the past 10 years. NET $365K. Property ID # 5265.

**LAGUNA NIGUEL** — Coming Soon!

**LA QUINTA** — Price Reduced!! Well established GP with over 8 years of goodwill. This modern designed practice has 8 eq ops. On the busiest major intersection. Grossed approx. $1.6M for 2018. NET $568K. Property ID #5243.

**TORRANCE** — Located right off the PCH, this GP is Collecting $43K in monthly revenues. Net of $123K. Property ID #5281.


**CARMEL VALLEY** — Price Reduced! Turn key practice with 3 eq ops and 1 plumbed not eq on an approx. 1,815 sq ft suite. PPO and Cash only. Grossed approx. $325K in 2018. ID # 5274.

**RIVERSIDE COUNTY**


**LA QUINTA** — Price Reduced!! Well established GP with over 8 years of goodwill. This modern designed practice has 8 eq ops. On a approx. the busiest major intersection. Grossed approx. $1.6M for 2018. NET $568K. Property ID #5243.


Workers’ Compensation: Your Obligations as an Employer

TDIC Risk Management Staff

The responsibilities of dental practice owners extend far beyond patient care. As an employer, you also have an obligation to ensure you are following workers’ compensation laws. Workers’ compensation insurance provides state-mandated benefits to employees who suffer an injury or illness that arose out of or occurred in the course and scope of employment. Your insurance carrier can help you determine the specific obligations in your state, such as compliance postings, statute of limitations and injury reporting requirements.

Other local, state and federal leave laws run parallel and at times intersect with workers’ compensation laws. The Dentists Insurance Company offers workers’ compensation coverage to California Dental Association members, and TDIC’s Risk Management team has answered a wide range of questions that relate to workplace injuries and illnesses, leaves of absence, workplace accommodations and termination. The following are a few common scenarios related to workers’ compensation that have been addressed by analysts.

Scenario 1: Notification of a Workers’ Compensation Injury by a Doctor

A front-office staff member was injured at work. The employee did not notify the dentist that she had sustained an injury, was currently receiving medical treatment or that she was scheduled for upcoming surgery. To compound the situation, the employee had performance issues that were well documented in her personnel file. The employee had been counseled on several occasions regarding her attendance and arriving late for work. On this occasion, the employee failed to show up for her scheduled shift. The office manager called the employee to determine why she hadn’t arrived, but was unsuccessful in making contact with her. Later that day, the office received a fax from the office of an orthopedic surgeon advising that the employee would be off work for several months. Eventually, the office manager reached the employee,

Your insurance carrier can help you determine the specific obligations in your state, such as compliance postings, statute of limitations and injury reporting requirements.

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who stated that the communication from the orthopedic surgeon stemmed from a back injury she sustained at work. The office manager and the dentist were shocked by the employee’s assertion that she sustained a workplace injury, as she had not earlier provided any notice to the office. The office followed normal protocol in assisting the employee to file a claim for workers’ compensation benefits. While the office attempted unsuccessfully to obtain more information regarding the employee’s medical leave, the employee did send multiple text messages stating that she was unable to return and needed to extend her leave. The employee’s absence created a strain on overall office operations, and the office ultimately decided to terminate her employment.

In California, even if an employee is terminated due to personnel issues, their workers’ compensation claim can continue. TDIC’s Risk Management analyst recommended that the office consult with an employment attorney for advice on how to proceed.

If facing a similar scenario, TDIC recommends the following:

■ Immediately notify your carrier of an injury involving an employee to begin the process of filing a workers’ compensation claim.

■ While workers’ compensation laws vary from state to state, most states generally require employers to provide a workers’ compensation claim form to the employee within one working day after becoming aware of the work-related injury or illness. In California, for example, once you have knowledge of the injury, you have 24 hours to provide your employee with a DWC-1 claim form. Additional information on state-specific workers’ compensation laws are available on the U.S. Department of Labor’s website at dol.gov/owcp/dfec/regs/compliance/wc.htm.

■ Continue to engage with your employee throughout their leave and attempt to check in with the employee every 30 to 45 days to obtain a work status report. The employee should also advise you of the date they expect to return to work. If the employee is not communicating with your office, document your attempts in the employee’s file.

Scenario 2: Filing a Workers’ Compensation Claim After Termination

A morning huddle at an office didn’t begin well and actually ended with two employees arguing about a patient scheduling error. One of the employees left immediately after the meeting without notifying anyone. The office manager attempted to contact the employee, but the employee refused to speak to her and simply hung up. The employee did not return to work or notify the office for the remainder of the week. The following week, the office sent the employee a letter recounting her actions and informed her that they were therefore accepting her resignation. Several weeks later, the employer received a letter from a workers’ compensation attorney representing the ex-employee. The letter advised that the employee was filing a cumulative trauma claim related to pain in her neck, shoulders and thigh, as well as mental stress.

If facing a similar scenario, TDIC recommends the following:

■ Engage in required discussion with an injured employee and obtain medical work status reports and assist with the employee’s return to work. However, know that this is not required once the injured worker is no longer your employee.

■ Notify your carrier of an injury involving an employee to begin the process of filing a workers’ compensation claim.

■ Know that in California if an employee was terminated and is represented by an attorney, the assigned workers’ compensation adjuster will ensure that the employee is treated by a physician in the medical provider network (MPN). As an employer, you do not need to authorize treatment for the employee.

■ Continue to cooperate with the insurer and third-party administrator during the investigation of a claim, such as providing a copy of the employee’s personnel file and statements to the defense attorney. All evidence will be used to provide the defense of the claim.

Every claim is unique and is based on the specific facts and events leading up to the employee’s workplace injury. After filing a workers’ compensation claim, be sure to stay in contact with your carrier so you may better understand regulations, processes and your role as an employer.

■ Be familiar with employer-required postings and employee notifications, as you are required to ensure your employees are aware of workers’ compensation and the benefits it may provide.

■ Notify your carrier or third-party administrator within 24
4359 SANTA CRUZ GP offering 30+ years of goodwill within walking distance to the beach! Located in a well-established, attractive, single story professional building complex w/ ample parking, good visibility and easy access. 2 doctor days/week, 2 hygiene days/week, 380 active patients with approx. 10 new patients/mo. 3 fully equipped ops in 850 sq. ft. Average GR $250K with Average adj net of $135K. Asking price $150K.

4351 SEBASTOPOL AREA GP & BLDG. Charming practice situated amidst rolling hills, soaring redwood trees and lush vineyards. Where coffee shops roast their own beans, dining options vary from down-home to gourmet, and people are friendly. Offering 70+ years of goodwill. Beautiful, modern facility with 3 fully-equipped ops (room for a 4th op) and digital x-ray. Equipment in pristine condition, most purchased 2016-2018. Dental suite has lots of natural light with views looking into a courtyard and garden. 2019 GR annualized at $679K+ with adj. net of $210K. Average 3.5 doctor days/week and 4 hygiene days/week. 800 active patients, all fee-for-service. Seller owns the building, it is available for purchase. Asking $305K for practice, $425K for building. Owner/doctor willing to help for smooth transition.

4338 PENINSULA PROSTHODONTIC PRACTICE Preeminent 45 year Prosthodontic practice located in mid peninsula neighborhood. State-of-the-art 2,022 square foot facility with 5 operatories. Seller willing to help in the transition. Outstanding referral sources. Average Gross Receipts $1.3M with 4 doctor-days per week. Asking $884K.

4256 SANTA CRUZ COUNTY GP Seller moving out-of-state and offering 33 years of goodwill. Wonderful location on major thoroughfare in a charming beach community close to wineries and the water. Tranquil and majestic, beautifully appointed, 5 op facility. Approx. 1,300 active patients (all fee-for-service). Seller will help for smooth transition. Asking $180K.

4343 CAPITOLA GP Gorgeous, state-of-the-art practice offering 33+ years of goodwill. Beautifully appointed office environment and building, located within minutes of charming downtown Capitola, known for its colorful, seaside shops and restaurants tucked into a hillside along Soquel Creek. Must see this office to appreciate its splendor. EZ freeway access, 5 fully equipped ops. 850-900 active patients (all fee-for-service). 4 doctor days/4 hygiene days per week. 2018 GR $928K with adj. net of $328K. Seasoned staff willing to stay on and Owner/Doctor willing to help for smooth transition. Asking $643K for practice. Seller owns building, it is available for purchase, or to lease.

4261 CAPITOLA GP Retiring doctor offering an established practice in professional office complex built around a garden setting. Average gross $743K+ with 4 doctor days and 6 hygiene days per week. Asking $562K.

4355 SAN FRANCISCO ENDO Endodontic practice in signature building with wealth of referral sources. State-of-the-Art, modern, 1,027 square foot office with 2 fully equipped ops. Well established, seller with sterling reputation willing to help for smooth transition.

4331 SAN FRANCISCO GP Downtown SF practice in gorgeous, remodeled 1,300 office with panoramic views. Suite includes 4 fully equipped ops, reception area, business office, private office, staff lounge, lab area, and sterilization area. Beautiful, modern cabinetry and equipment. 1,600 active patients with 15-20 new patients/mo. Owner/doctor works 3 days/wk with 5 hygiene days/wk. Average gross receipts $738K with average adj. net of $305K. Asking $495K.

4358 SAN MATEO GP Unique opportunity to own a downtown San Mateo GP surrounded by a variety of retail, restaurant, service and specialty shops generating significant foot traffic and daily business draw. 1,486 square foot facility with 4 ops, reception area, business office, private office, staff lounge, lab area, sterilization area, bathroom, storage & dedicated parking spaces. Family oriented practice with an emphasis on Restorative care. Average annual Gross Receipts $400K+.

4336 SAN BRUNO GP Legacy practice centrally located in a combined commercial & residential neighborhood, convenient to highways 101, 280, and 380 and close to the BART station. Elegant, remodeled 1,498 sq. ft. office with 5 fully-equipped ops. & digital radiography. Average Gross Receipts $922K+. 1,000 active patients with an average of 10 new patients per month. Asking $661K.

4216 SIERRA NEVADA FOOTHILLS 23 year practice located in the heart of the Sierra Nevada foothills in modern building close to downtown area. 1,024 square foot office with 4 fully-equipped ops., upgraded major equipment and digital radiography. Average Gross Receipts $890K+ with over 50% average overhead. Asking price for practice $604K. Seller is offering real estate for sale to the buyer of his practice.

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hours of your notification of the work-related injury so a claim can be set up immediately.

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- Contact your carrier to determine where you can send your employee for their first medical visit and subsequent care. In the event your employee needs immediate medical care, do not hesitate to call 911 or send the employee to the nearest emergency room.
- Do not treat employees who file workers’ compensation claims (and those returning to work after an injury or claim) differently than other employees. This will eliminate the potential for an allegation of discrimination based upon filing a workers’ compensation claim.
- Engage in an interactive discussion with your employee to determine if you can accommodate temporary work restrictions and provide transitional work (light duty) while the employee heals from the injury. Document your discussions in writing, as the notes could be used as part of the claim process and determination of benefits.

For guidance specific to your practice’s situation, contact TDIC’s Risk Management Advice Line at 800.733.0633. You may be referred to an employment attorney for matters dealing with personnel issues and termination. If your employee seeks legal representation, your workers’ compensation carrier should obtain a workers’ compensation attorney to defend your case. If you have questions about your policy or coverage options, contact your carrier directly.
NORTHERN CALIFORNIA

CONCORD: East Bay, Digital, 3 Ops, modern, attractive bldg and space, PPO, 1,200 sf, Dentrix. 2018 GR $135k on 34 day. Dr. h/wk. #CA595

CONTINENTAL COUNTY: Goodwill: Records for only the Peds and/or Ortho portion of Practice. 11 yrs. Goodwill. Buyer must be within 15 miles of Contra County. Asking Price is below appraised value. #CA576

FREMONT: 4 Ops in approx. 1,300 sf, Downtown location w/ 2,000 sf. Goodwill. Seller owned facility, 2018 GR of $802K, 4 hyg/day wk. Dexis Digital X-ray, Dentrix PM, I/O Camera, Laser. MOVE-IN READY, this will not last! #CA564

SONOMA COUNTY: Community: Large GP offering a wide range of service, 8 Ops in 2,200 sf, space. Goodwill. Doctor current and will work back. Paperless, Digital, hi-tech, new equipment. #CA582


YUCCA VALLEY: New Listing! 2018 GR $1.8M. 4 Ops, Full paid Digital X-rays. Most specialty referred out there is room to grow. Bright, Cherry wood, space, EZ Parking. #CA593

SAN BERNARDINO: New Listing! Great location. Digital X-ray, 35 hrs h/wk, 2018 GR $470K. #CA573

Bakersfield area: New Listing! 5 Ops, 2 Dr. and 4 hyg/day wk. Most specialty referred out. Room to grow! Real estate also available to purchase. 2018 GR $715K. #CA623

Bakersfield Peds: Rare partnership opportunity at a successful 30+ yr. old Peds practice with ortho and oral surgery services. Over 4K active patients, averaging 40 NP per month. GR $2.5M for the past 3 yrs. #CA459

Burbank: 4 Ops, 2 Dr, 2018 GR above $575K. Modern, prof. designed suite w/ great location in 2016. 2018 GR $202K. #CA575

COVINA: New Listing! GR $580K, 5 Ops, Digital X-rays. Most specialty referred out. Great location. #CA593

Southern California

Bakersfield area: New Listing! 5 Ops, 2 Dr. and 4 hyg/day wk. Most specialty referred out. Room to grow! Real estate also available to purchase. 2018 GR $715K. #CA623

Bakersfield Peds: Rare partnership opportunity at a successful 30+ yr. old Peds practice with ortho and oral surgery services. Over 4K active patients, averaging 40 NP per month. GR $2.5M for the past 3 yrs. #CA459

Burbank: 4 Ops, 2 Dr, 2018 GR above $575K. Modern, prof. designed suite w/ great location in 2016. 2018 GR $202K. #CA575

COVINA: New Listing! GR $580K, 5 Ops, Digital X-rays. Most specialty referred out. Great location. #CA593

San Gabriel Valley: 4 Ops, Digital X-rays, 65 yrs. Goodwill. Most specialty work is referred out, most PPO plans are accepted. Busy road with great visibility, open 4 days/wk. Nicely appointed; excellent opportunity. #CA596


SIMI VALLEY: New Listing! 3 Ops, 30+ yrs Goodwill. Older 1,100 sf. office in strip mall shown Room to grow! Dental area. Most Specialty procedures referred out. 2018 GR $263K, #CA626

South Bay: LOS ANGELES AREA: High income area. Priced well w/ hi-end shopping ctr. 5 Ops, Digital X-ray, SoCal Dental, Long-term staff, 2018 GR $740K $310K Adj. Net. #CA589


San Diego


North County PERIO: 4 Ops, 3 Equip. New equipment including a CT Scanner, Digital and Dentrix. Excellent location in a well maintained complex. Priced to sell. 2018 GR $783K. #CA617

San Diego County Ortho: New Listing! Works out of 2 sites over 4 days/wk. Bldg. on corner of a main road with great visibility, open 4 days/wk. Nicely appointed. #CA616

San Diego County ORTHO: New Listing! Works out of 2 sites over 4 days/wk. Bldg. on corner of a main road with great visibility, open 4 days/wk. Nicely appointed. #CA616

Out of California

Central Oregon: Family-oriented GP practice located in a busy shopping area. Newly refurbished, 3 Ops with new equipment, Digital X-rays, Upgraded 2D Panorads, Dentrix. Excellent opportunity. Seller is relocating. #CA618

Hawaii: WAIMEA OPMS: Practice: 6 Ops. Consistent GR of $180K for past 3 yrs. Convenient location with ample free parking. PPO, HMO, and PFS. Priced to sell. #CA619

South Coast, OR: New Listing! New location off Route 101 8 miles from the ocean. Dr works 3 days/wk, 2 days hy/wk. 2018 GR $376K. #CA620

South Coast, OR: New Listing! Turnkey, 2.300 sq. ft. offices, EagleSoft, Digital, Pano. 2018 GR $740K. Bldg. avail. #CA618

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Specialists in the Sale and Appraisal of Dental Practices
Serving California Dentists since 1966
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6169 VACAVILLE  Long established Delta PPO practice. 5-days of hygiene. 2019 trending collections of $700,000+ with Available Profits of $250,000. Great northside location.

6168 SACRAMENTO’S CAMPUS COMMONS “Bread & butter” Delta PPO practice averages $480,000 in collections per year. Well liked Dentist. 10+ weeks off a year. 4-days of Hygiene. 3-D Cone Beam. Integrate implants here as retirees in area require this service. Full Price $200,000.

6167 NORTH SANTA CLARA COUNTY - “OUT-OF-NETWORK” Perfect for Skilled Dentist who seeks strong patient relationships and wants to be insurance independent! 2019 trending $800,000+ - 5-days of Hygiene. Entire office has been upgraded and charting is paperless.


6165 ROSEVILLE ORTHO – “OUT-OF-NETWORK” Stanford Ranch. Great satellite office. $455,000 invested in build-out, furnishings, computers and equipment. 3-chair Bay. Digital Pan with Ceph. 51 active patients and averages 3 New Patients per month. Full Price $150,000.

6164 SAN FRANCISCO BAY AREA - “OUT-OF-NETWORK” Highly regarded practice as evidenced by 25+ new patients per month. Collections have topped $2 Million in each of the last 3-years with enviable Profits. Paperless. 3D Cone Beam. Great location. Seller shall work-back to affect an orderly transition. Rare opportunity for that Dentist seeking a Super Platform to practice their craft at the highest level.

6163 LAKEPORT  Attractive option to practicing in ultra-competitive settings in expensive housing markets. Appeal of practicing in Lakeport is ability live a less hectic life. Decompress, have more time for yourself. Beautiful 6-op facility with high-end technology and completely networked. 2018 collected $956,000 with Profits of $360,000. 2019 trending $1.1+ Million in collections. Building optional purchase. Full Price $295,000.

6162 REDDING  Great alternative to practicing in uber-competitive markets in ultra-expensive housing communities. Strong foundation evidenced by 1,500+ patients and 8-days of Hygiene. Charges totaled $709,800 in 2018 - down from 2017 which realized $779,000. Owner chooses to work less and takes 9-weeks off. "Bread & butter” practice. All specialty work referred. Roll-up sleeves and do $1+ Million if you choose. Patients are here. Seller previously owned very busy Group Practice in Orange County beach community. Comparing both, he prefers his Redding practice. 2,000 sq.ft. suite leases for $2,296/month and enjoys river views. Full Price $175,000.

6158 FORTUNA Relaxed lifestyle in Humboldt County’s Banana Belt. Adjacent to Ferndale. Perfect for Dentist seeking small town living. 2018 Collected $395,000 with $156,000 in Profits. 2019 trending $400,000+. 6-weeks off. Lots of work referred. Full Price $75,000.

6157 SACRAMENTO’S ELK GROVE AREA - “SOLD” 2018 collected $909,000 on Owner’s 3-day week. Successor can increase to 4-days as practice is rich in patients. 25+ new patients per month. 5-ops, digital Pan, strong Recall, great staff.

6152 SAN RAFAEL - “SOLD” Across from Marin Academy. 2018 collected $520,000. Stand-alone building optional purchase. Nearby DDS who desires their own building should vertically integrate their practice here and have instant $1+ Million practice in superior location.

6147 SAN FRANCISCO BAY AREA - “OUT-OF-NETWORK” - “SOLD” 2018 collected $2.2 Million. Hygiene produced $1+ Million. $700,000+ in profits. Seller available for long transition.

4000 SOUTH ORANGE COUNTY - FEE FOR SERVICE High profile Shopping Plaza. Can do $2 Million with energized Buyer & Associate. Grosses $1.45 Million.

4001 PALM SPRINGS / LA QUINTA - Location, Location, Location! GROSSING $1.5 Million. Well equipped. High identity. $2 Million achievable.

4002 PEDO CHINESE / HISPANIC 3,000 Charts. Established 35 years. Move into your nearby office. Full Price $150,000.

4003 INLAND EMPIRE – UNION PRACTICE Can do over $1 Million. 5 ops.

4005 REDLANDS HISTORIC COLLEGE CITY Long established, moved into new condo in 2015. Beautiful 6-ops. New equipment & cone beam. Seller will transition 2 days/week at $500 per day for 2 years. Grosses $961,000 on 2.5 day week. 3.5 hygiene days. $5,000/month in HMO. Nets $400,000. Can grow to $2 Million. Full Price Practice $961,000. Condo $1,100,000.

4006 ALTA LOMA High identity shopping center. Grosses $700,000 with Absentee Owner. Hands-on Successor will do $1 Million. 5 ops, 3 equipped.

4007 WEST COVINA Grosses $650,000. 2 days Hygiene. Absentee owned.

4009 IRVINE Lady DDS grossing $1 Million. 5 Ops.

4011 DIAMOND BAR Dream Million Dollar location. 5 ops equipped. Several restaurants bring in droves of customers daily. Full Price $150,000.

4013 ORANGE COUNTY BEACH CITY Grossed $70,000 last month. 4 ops in 1,800 sq.ft., room for more. Seller will transition. Full Price $800,000.

4014 VENTURA CITY Grossing $1.6 Million, HMO $100,000 month.

4015 HEMET Easy way to gross $500,000. Grossing $180,000 on 1-day. Seller must sell. Building & Practice. Full Price $110,000.

4018 SOUTH ORANGE COUNTY Two separate practices doing approximately $800,000 each. Owned by same DDS.

4019 $1 MILLION NET PROFIT Opportunity of a lifetime. Phone Tom at 714-832-0230.

4022 VENTURA Cash and PPO. 4 days Hygiene, 4 ops. Trending $620,000+.

4023 ORANGE Grossing $380,000 on 3-days. 1.5 days of Hygiene. Lease up in 6 months. 3-year options. Close to Chapman and Tustin streets.

4024 WEST LOS ANGELES Prestigious Medical building. 39-years established. 4-ops.

4024 LA HABRA / LA MIRADA Professionally designed office. Next to several fast food restaurants. Cash, PPO, some Denti-Cal. HMO $3,000 per month. Grossing $520,000+.

4027 IRVINE - NEWPORT BEACH - SOUTH SANTA ANA - COSTA MESA - Tustin  Dentist retiring. Lost Lease. Will work back. $800,000 Fee for Service.

4028 BAKERSFIELD AREA Grossing $40,000 on 2 day week. 1,800 sq. ft. 5 op. Full Price $230,000 includes RE.

4029 CAPISTRANO BEACH Senior DDS. Grosses $200,000 on 16-hours. Full Price $150,000.

4030 INLAND EMPIRE DentistCal grossing near $300,000. 4 ops Rent $1,350. Full Price $195,000.

4031 INLAND EMPIRE – UNION PRACTICE Grosses $650,000+. Nets approximately $400,000 on 2.5 days.

4032 LAGUNA WOODS Absentee owned. Grossing close to $800,000. High end area. High identity shopping center.


4034 ORANGE COUNTY BEACH CITY Absentee owned. Grossed $934,000 in 2018. Working owner shall do $1 Million first year.

4035 REDLANDS 5 ops. Grossing $500,000. Low overhead. Long established.

4036 RIVERSIDE Female grossing $300,000. 3 ops. Full Price $250,000.

4037 SANTA CLARITA DDS wants to share and remain 1-day in 2 ops. 8 ops available. 70,000 autos pass daily. This location did almost $2 Million with previous owner.

4038 VAN NUYS Starter Practice. Over 2,500 Patients. $150,000 or Make Offer.
dentist, “Dr. Defgh,” is retiring after 25 years of practice due to a permanent disability. Several years earlier, she had switched from using paper charts to an electronic health record system. What is Dr. Defgh required to do with her patients’ information upon retirement?

The answer depends on what she will do with the practice. Her options are to close it, to sell the practice in its entirety or to sell or otherwise transfer only the patient records to another dental practice. For purposes of this article, Dr. Defgh is a HIPAA-covered entity.

Practice Closure

California law requires health care providers ceasing operations to retain records for at least seven years from the date a patient was discharged or last seen. With regard to the records of unemancipated minors, the records must be kept at least one year after the minor has reached the age of 18 years and, in any case, not less than seven years.¹ A professional liability carrier may recommend retaining the records for a longer period.

Dr. Defgh and her staff should take these steps:

Notify active patients (those seen in the practice in the past two years) of the dentist’s retirement and of the process for obtaining a copy of their records for their new dentist. Include a release of records form with the notice.

Pull paper charts of patients who have not been seen in more than seven years. Check for records located at off-site storage, if used. Separate radiographs from paper. Shred paper or use a document destruction service. For disposal of radiographs, contact an X-ray film recycler or the local household hazardous waste program that accepts waste from very small-quantity generators. Because radiographs contain silver, state law requires proper disposal or recycling. Dr. Defgh must have a HIPAA business associate agreement with each of these service providers.

Prepare paper charts for storage by organizing them by year and then alphabetically by patient name. Identify a secure storage area for the charts. Dr. Defgh also needs to consider who will retrieve records if needed — herself or an employee of the facility where the charts are stored. A HIPAA business associate agreement must be obtained from any third party that stores the records.

Determine when to end use of the electronic health record software. Create PDF documents of each electronic patient chart and have them stored on an encrypted device. The PDF copies allow the dentist to email or to print and send records to patients who request copies. Ensure any unencrypted patient information is wiped from devices.

In case of a malpractice claim, Dr. Defgh may want to retain a secure archival copy of the software and all documentation. If this was not included in the original software contract, she should inquire with the software company. According to the Office of the National Coordinator for Health Information Technology:

“The (contract language) could be important to you in the defense of a medical malpractice claim since it may be necessary to use an old version of the EHR vendor’s software to determine what information could have been available to a health care professional who reviewed a patient’s records at a particular point in time. If your EHR vendor provides the EHR as a service under a cloud model, you typically would not have received the software. Therefore the EHR contract should impose an obligation on the vendor to maintain copies of all software versions and to provide services to facilitate your access to the software in the circumstances discussed above. You could include a mechanism in your EHR contract to pay a reasonable amount for these services (if the vendor required).”²

Practice Sale

Dr. Defgh is successful in finding a buyer for her practice. With regard to her patients’ records, she and her staff should take the following steps.

Notify active patients (those seen in the practice in the past two years) of the dentist’s retirement and of the transition to the new practice owner. Include a partially completed release of records form that the patient can sign and return indicating authorization to release their record to the new owner. Authorization is implied if a patient who did not return the release of records form makes an appointment to be seen by the practice. Patient authorization in this regard is a requirement of California law and not of HIPAA.

Reach an agreement with the buyer on the disposition of patient records. It is likely the buyer will want to keep only the active patient records but may end up with all of Dr. Defgh’s records. Whoever has physical possession of the records is responsible for its security and proper disposal, according to California law. In case of a malpractice claim, Dr. Defgh should arrange for access to her records for a recommended period of 10 years.
Contact the electronic health record company to arrange for transfer of the software license to the new owner. If the new practice owner thinks they may switch later to a different electronic health record system, they will need to ensure appropriate contract language is included to allow for the transition. Dr. Defgh should arrange for an archival copy of the software and information as described previously.

Transfers Records
Dr. Defgh is not successful in finding a buyer for the practice but finds a dentist who is willing to store the patient records and to fulfill patient access to record requests. Dr. Defgh and her staff should:

- Separate the charts as described previously and dispose materials appropriately.
- Agree to formal terms for records storage and retrieval, fees, access by Dr. Defgh and procedures permitting the other dentist to convert Dr. Defgh’s patients to their practice. The terms should include a requirement that a patient sign an authorization releasing their record to the other dentist. If that dentist has no interest in converting the patients to their practice and is simply providing a records storage and retrieval service, a HIPAA business associate agreement should be signed.
- Notify patients of Dr. Defgh’s retirement and include a release of records form. The notification should include the date when the other dentist will start fulfilling patient access to record requests.
- Arrange for PDF copies of patient charts as described previously. Provide an encrypted drive with the patient records to the other dentist per agreement.
- In case of a malpractice claim, arrange for access to Dr. Defgh’s records for a recommended period of 10 years and arrange for an archival copy of the electronic health record and documentation as described previously.

Death or Incapacity of a Dentist
If Dr. Defgh was suddenly unable to practice, California law would allow her estate or legal representative to operate the dental practice for no longer than 12 months under specified conditions, which include notifying the dental board.3 The estate or legal representative must notify patients of the dentist’s death or incapacity within 30 days of the event and provide any relevant information about the continuation of the dental practice. The dentist or dentists contracted by the estate or legal representative to operate the practice must obtain patients’ signed authorization releasing records to the dentist or dentists.

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Regulatory Compliance appears monthly and features resources about laws that impact dental practices. Visit cda.org/practicesupport for more than 600 practice support resources, including practice management, employment practices, dental benefits plans and regulatory compliance.
QUESTIONS MOST OFTEN ASKED BY SELLERS:

1. Can I get all cash for the sale of my practice?
2. If I decide to assist the Buyer with financing, how can I be guaranteed payment of the balance of the sales price?
3. Can I sell my practice and continue to work on a part time basis?
4. How can I most successfully transfer my patients to the new dentist?
5. What if I have some reservation about a prospective Buyer of my practice?
6. How can I be certain my Broker will demonstrate absolute discretion in handling the transaction in all aspects, including dealing with personnel and patients?
7. What are the tax and legal ramifications when a dental practice is sold?

QUESTIONS MOST OFTEN ASKED BY BUYERS:

1. Can I afford to buy a dental practice?
2. Can I afford not to buy a dental practice?
3. What are ALL of the benefits of owning a practice?
4. What kinds of assets will help me qualify for financing the purchase of a practice?
5. Is it possible to purchase a practice without a personal cash investment?
6. What kinds of things should a Buyer consider when evaluating a practice?
7. What are the tax consequences for the Buyer when purchasing a practice?

Lee Skarin & Associates have been successfully assisting Sellers and Buyers of Dental Practices for nearly 30 years in providing the answers to these and other questions that have been of concern to Dentists.

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Top 10 Issues For Dentists

Complaining Retirement

In Ten Years or less

Timothy G. Giroux, DDS

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BAY AREA

AC-989 SAN FRANCISCO (facility): Busy Retail Shopping Plaza w/ major anchor tenants! 3 ops $125k
AC-1059 DAILY CITY: Amazing practice w/ seasoned staff in highly desirable neighborhood. 1500 sf w/ 4 ops $345k
AG-871 SAN FRANCISCO: Seller Motivated! ~600 sf w/ 2 ops Price Reduced $65k
AG-944 SAN FRANCISCO: An opportunity like this does not come along very often! ~980 sf w/ 3 ops Reduced $575k
AG-945 SOUTH SAN FRANCISCO: Be a part of this vibrant, diverse population. ~1800 sf w/ 4 ops $495k
AG-990 SAN FRANCISCO: Build the practice of your dreams! ~850 sf w/ 3 ops $228k
AG-993 WEST PORTAL AREA: Desirable area w/ easy commute to downtown San Francisco. ~1000sf w/ 3 ops Reduced Price: $410k
AG-994 SAN FRANCISCO: Highly profitable with net profit over $400k! ~850 sf w/ 3 Ops $825k
BC-741 DANVILLE (facility): Move in Ready! ~1600 sf w/ 3 ops. PRICED TO SELL! $10k
BC-926 ANTIOCH: Long established, well respected office. 1866 sf w/ 5 ops $495k
BC-949 ALBANY: Desirable commercial/residential area. Medical Prof Bldg w/ good frontage. 3200sf w/ 4 ops $695k Real Estate: $1.8
BC-1010 ANTIOCH: Amazing Opportunity in Health Prof. Complex 2118 sf w/ 2 equipped ops + 3 add’l $250k
BC-1022 OAKLAND: “Pill Hill” Area adjacent to hospital! 1064 sf & 2 ops. Plumber for 1 add’l! $150k
BC-1056 SAN RAMON (facility): Move-in ready! Well maintained prof complex. 1698 sf w/ 4 ops $100k
BG-981 BERKELEY: Long established, family-oriented practice. ~1100 sf w/ 3 ops $345k/ Real Estate $490k
BG-1025 WALNUT CREEK: You won’t find a more outstanding opportunity than this extraordinary practice! ~1218 sf w/ 6 ops. $750k Real Estate: $995k
BN-952 BERKELEY: Don’t hesitate on this incredible opportunity! ~835 sf w/ 3 Ops. Seller Motivated $200k
BN-1023 RICHMOND: This is a rich opportunity for the astute dentist! 1450sf w/2 ops + 2 add’l. $50k/ Real Estate $750k
BN-1038 BERKELEY: A perfect opportunity to own a practice in one the Bay Area’s most popular cities! 1000sf w/3ops. $385k
BN-1045 CONCORD: Imagine owning a highly successful, family-oriented practice! 1150sf w/ 3 ops. $165k
CC-846 SAN RAFAEL: Prof/Retail Building Complex. 3 ops 640 sfollections $433k in 2017 $275k
CC-927 SAN RAFAEL: Build the practice of your dreams by increasing this 2-day work week! 800 sf w/ 3 ops $175k

BAY AREA CONTINUED

CC-960 SONOMA: Great location in one-of-a-kind setting! 950 sf w/ 3 ops. $385k/ Real Estate Available $350k
CC-979 NOVATO: Seller Retiring. 803 sf w/ 3 ops near downtown and Old Town Novato. $195k (Real Estate $215k)
CC-1017 VACAVILLE: Maximize your work days and watch your production increase! ~ 1500 sf w/ 4 ops $130k
CC-1020 SANTA ROSA: Cash Flow of over $270k. Unique FFS Practice. 1320 sf w/ 4 ops. $450k
CC-1030 SANTA ROSA: Condo office in modern bldg w/ ample parking & adjoining Ortho practice! 1683 sf w 5 ops $325k
CC-1049 SANTA ROSA: Fully Remodeled, Amazing Location. 2000 sf w/ 5 ops $685k Real Estate Also Available
CG-616 NAPA COUNTY: State-of-the-Art office! ~850 sf w/ 2 Ops. Price Reduced – Seller Motivated $250k
CG-995 VALLEJO: Live, play and practice here where your lifestyle can’t be beat! ~2035 sf w/ 7 ops $1,175M
CG-1037 SONOMA COUNTY: Your lifestyle and practice will indeed be the envy of many dentists! ~1310 sf w/4ops $395k
CG-1048 SONOMA: This highly successful family-oriented practice has it ALL! ~1500 sf w/ 4 ops $650k
CN-911 SANTA ROSA: “Quality Care & Patient well-being FIRST”. 2250 sf w/4 ops + 1add’l. Now: $520k
DG-862 MID-PENINSULA: Rare gem with up to 7 operatorys in the Bay Area! ~2274 sf w/ 6ops + 1 add’l. $475k
DG-936 SUNNYVALE: Hesitate and you may lose out on this opportunity of a lifetime! ~1000 sf w/ 3 ops $495k
DG-986 CAMPBELL: The ~988 sf w/ 3 ops Seller Motivated $288k
DG-1006 MONTEREY AREA: This practice is one which every dentist aspires to! ~3400 sf w/ 8 ops $1,395M
DG-1009 CARMEL: Amazing fee-for-service practice w/ no contracts! ~1150 sf w/ 4 ops $625k
DG-1014 MONTEREY: Don’t miss your opportunity to live and practice in beautiful Monterey! ~1125 sf w/ 4 Ops. $875k
DG-1034 BELMONT: Med Prof Bldg on bustling commercial corridor. ~2000 sf w/ 5 ops $425k
DG-1035 LOS GATOS: Over 40 years Goodwill in this charming community! ~1010 sf w/ 4 ops. $790k
DG-1040 SUNNYVALE: Don’t hesitate on this remarkable opportunity! ~3477 sf w/ 6 ops $1,085M Real Estate Available
DG-1042 MOUNTAIN VIEW: Amazing opportunity providing quality, high-end dentistry! ~ 890 sf w/ 3 Ops CALL FOR DETAILS

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Complaining Retirement In 10 years or less

Timothy G. Giroux, DDS

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**NORTHERN CALIFORNIA**

**EC-1005 YOLO CO:** Highly Successful w/ Great Reputation in the Community! 1239 sf w/ 3 fully equipped ops $720k

**EG-910 MIDTOWN SACRAMENTO:** A thriving practice does not come along very often! ~1107 sf w/ 2 + 1 addl’. Reduced $210k

**EG-968 SACRAMENTO:** Desirable, mid-town neighborhood, w/ ample parking in garage! ~1527 sf w/ 5 Ops. Reduced $480k

**EG-972 ELK GROVE:** Prime location! Real Estate available to purchase in the future! ~3500 sf w/ 8 Ops. Reduced $495k

**EG-1012 EAST SACRAMENTO:** A practice like this one does not come available very often! ~2900 sf w/ 8 Ops. $2.5M

**EG-1016 LINCOLN:** Look no further than this growing community to spring-board into your success! ~1800 sf w/ 4 Ops Reduced $570k

**EG-1039 EL DORADO HILLS VICINITY:** The ideal opportunity to practice in this community! ~1100 sf w/ 4 Ops. $350k

**EG-1061 SOUTH AUBURN VICINITY:** Come live, play and practice in the heart of this pristine town! ~1100 sf w/ 4 Ops. $350k

**EN-1051 SACRAMENTO:** Location, Accessibility and Quality Relationships! 1,671sf w/ 5ops. $395k

**EN-1052 EAST SACRAMENTO:** Remarkable, long-established opportunity, loaded w/ goodwill! 1100 sf w/ 4 ops. $950k

**EN-1055 ROCKLIN Facility:** Build your own success here in this family-oriented community! 1650 sf w/ 4 ops + 1 addl’. $95k

**FC-650 FORT BRAGG:** Family-oriented practice. 5 ops in 2000 sf $350k for the Practice & $400k for the Real Estate

**FG-841 ARCATA:** Great demographics w/ very little competition! ~1114 sf with 3 ops Reduced Price: $200k/ Real Estate Available

**FN-961 EUREKA:** Where the quality of life can’t be beat! 1400sf w. 4 ops. Practice Reduced: $395k/ Real Estate Available $395k

**FN-855 NO. HUMBOLDT:** Seller relocating! Long-established, 100% FFS practice! 1600 sf w/ 3 ops + 1 addl’. $190k/ Real Estate Available

**GN-953 CHICO:** Established for 55 years and the seller is passing their goodwill on to you! 1067sf w/ 3ops. Now Only $275k!

**GN-924 TEHAMA COUNTY:** Don’t miss this ideal opportunity! 3000 sf w/ 6 ops. Practice $495k / Real Estate $455k

**GN-988 YUBA CITY:** Excellent Merger Opportunity! Location and Lifestyle! 1,600 sf w/ 3 ops. $100k

**HG-1053 GRASS VALLEY:** Well-established practice of 40+ years, known for its quality dentistry! ~1200 sf w/ 3 ops $420k

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**CENTRAL VALLEY & SOUTHERN CALIFORNIA**

**IC-975 MODESTO:** Established 33 years. 1,100 sf w/ 3 ops $225k

**IG-881 TURLOCK:** Long established has unsurpassed quality care. ~3500 sf w/ 10 Ops (shared). Reduced: $295k

**IG-1007 GREATER MODESTO AREA:** Combines a quality learning environment with relaxed rural living. ~3000sf w/ 6 ops. $645k

**IG-1009 TRACY:** This opportunity is waiting for you to sink your roots down and invest your future here! ~1200sf w/ 4 ops. $745k

**IN-917 MERCED AREA:** Well established practice with a stable, loyal patient base! 1500 sf w/ 3 Ops. Reduced! $295k

**JC-811 FRESNO COUNTY:** Seller willing to consider Associateship for qualified DDS w/ intention to Buy In! ~3000sf w/ 6 ops. $350k

**JC-829 LOS BANOS:** Heavy emphasis on hygiene. 1000 sf w/ 3 ops $80k

**JC-1034 VISALIA:** Practice AND REAL ESTATE! Prof Bldg on major thoroughfare. 2,260 sf w/ 6 ops $275k/ Real Estate $517k

**KG-921 SANTA MARIA:** Live and practice in this desirable collegiate coastal community! ~930 sf w/ 3 ops. Seller Motivated $285k

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**SPECIALTY PRACTICES**

**BC-784 CENTRAL CONTRA COSTA CO Perio:** Seasoned Staff. Office runs like well-oiled machine! 3 ops $295k

**BG-843 WALNUT CREEK Perio:** Priced at 50% of collections! ~1085 sf w/ 4 ops $390k

**BG-1024 WALNUT CREEK Prosth:** Stellar reputation for providing the highest level of treatment! ~2138 sf w/ 6 ops. $750k Real Estate: $995k

**BN-998 WALNUT CREEK/SAN RAMON AREA Ortho:** Looking for your dream Orthodontic practice! 1450 sf w/ 5 Open bays/Chairs. $1.15M

**DC-835 TRI-VALLEY Perio:** Collections over $1.2M. 2,100 sf $800k

**DN-1044 FOSTER CITY Pedro:** Shared Space Situation. Conveniently located within walking distance of major corporations. 830sf w/ 3 ops. $195k

**GG-940 NORTH OF SACRAMENTO Pedro:** Practice is on track to collect more than $1,000,000 in revenues this year! ~3800 sf w/ 5 ops. Reduced $555k

**JG-757 VISALIA Perio:** Incredible Giveaway at this price! Collections over $800k! ~2000 sf w/ 5 ops Steal at $150k

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**BAY AREA CONTINUED**

**DN-1031 CUPERTINO:** This remarkable practice awaits only your talent and skill! 1500sf w 3 ops + 1 addl’. Reduced $1.1M

**DN-1032 PLEASANTON Facility:** The perfect place to live, practice & raise a family! 1400sf w/4ops. Includes CTScan! $185k

**DN-1041 SAN JOSE:** This stunning practice is an excellent opportunity for new grad! 1207sf w 2 ops + 1 addl’. $195k

**DN-1003 PLEASANTON Facility:** This is an excellent opportunity for a graduate or a dentist seeking a Satellite location. 1000sf w/ 3ops. $56k

**DN-1046 SANTA CRUZ AREA:** Opportunities like this does not come along, except once in a lifetime! Office 2050 sf w/ 5 ops. Total sq ft 3880. $595k / Real Estate: $1.1mil

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**NORTHERN CALIFORNIA CONTINUED**

**HG-815 TRUCKEE AREA:** Busy, productive practice with 3 days of hygiene! ~1000 sf w/ 3 ops $165k/ Real Estate $437k

**HG-983 GRASS VALLEY:** Newly remodeled office in highly desirable neighborhood! ~1250 sf w/ 3 ops. Reduced Price $195k/Real Estate Available

**HG-987 LAKE TAHOE AREA:** State-of-the-Art Practice located in picturesque mountain setting! ~ 3,400 sf w/ 6 Ops CALL FOR DETAILS

**HN-618 SIERRA FOOTHILLS:** Seller Retiring! Huge opportunity for growth by increasing office hours! 750 sf w/ 2 ops $65k

**HN-879 SONORA:** Great Cash-Flow for Only 3 Days a Week! 2950 sf w/ 3 ops Reduced Price: $265k

**HG-934 GRASS VALLEY:** Underworked PT base should support larger production numbers! ~1200 sf w/ 3 Ops Reduced $168,750/Real Estate Available

**HN-999 CALABEAS Co. (Facility/Real Estate):** 1,500 sf w/ 2 equipped Ops + 1 fully plumbed & 3 partially plumbed. $500k

**HN-991 PLACERVILLE:** Quality, conservative and compassionate practice! Will consider work back. 1,654 + 473 sf w 5 ops. $675k

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A look into the latest dental and general technology on the market

**Cash App** *(Free, Square Inc.)*

Cash App, from the makers of Square and available for iOS and Android, makes it easy to send and receive money from people, make purchases at merchants and even buy cryptocurrency.

Cash App is a service that requires a verified mobile phone number and/or email address to start. The account setup process is fast, and once the process is complete, users assign themselves a unique identifier called a $Cashtag to identify themselves to other Cash App users. The home screen is a simple interface to send and receive money to and from peers. Users enter a dollar amount and tap “Request” or “Pay,” specify a person using their name, phone number, email address or $Cashtag along with its purpose and then complete the transaction. With Bluetooth and app permissions enabled on mobile devices, users can also search for Cash App users close by. Funds are deposited or withdrawn from a Cash Card account, easily accessible using a button at the top of the home screen. The Cash Card can be funded from a bank account debit card at no charge. Users can also request a physical Cash App debit card to be sent to their mailing address, which draws from available funds in their Cash Card account. The Cash Card can also be added to Apple Pay Wallet, making it easy to make mobile payments at merchants. Cash App payments can also be made using a linked credit card, which will incur a 3 percent additional charge.

Unique to Cash App is the ability to easily purchase Bitcoin. From the Cash Card account view, users can select Bitcoin and see its current market price and year-to-date historical data. Users can then directly purchase or sell Bitcoin with available funds in their Cash App. There are no fees to buy or sell Bitcoin. Additionally, there are no fees to receive or send money to Cash App peers with available Cash Card account funds. Annual reporting forms for tax purposes from Bitcoin sold are available through the Cash App.

Easy-to-use, cross-platform and versatile in function, Cash App greatly reduces the need to carry physical cash in many cases. Because its primary function is a peer-to-peer payments service, all users must interact directly with the Cash App to take advantage of its features. Otherwise, users may still need to carry cash, which is still accepted everywhere.

— Hubert Chan, DDS

**IvoSmile** *(Free, Ivoclar Vivadent)*

Augmented reality (AR) is the technology that allows computers to overlay information onto the real world. Since 2013, AR has seen an explosion in use, and now companies like Amazon, Google and Disney have integrated it into multiple facets of their products. Without leaving their homes, consumers can see whether a new couch will fit in their living rooms, check out the latest fashions without having to try them on and test the latest gadgets without the gadgets themselves being physically present. Dentistry has taken notice of AR, and Ivoclar Vivadent has been a forerunner of AR’s clinical usage. This review focuses on the iPhone deployment of IvoSmile, which is a demo version of the application and does not fully reflect capabilities of the subscription-based iPad version of the application. An iPhone X was utilized for this review.

Released in 2018, IvoSmile for iPhone demonstrates the capabilities of its AR. Opening the application activates the front-facing camera and superimposes an outline of a head. The screen is divided into a left half and right half: The left half is labeled “Before” and the right half is labeled “After.” When a user’s smiling face is maneuvered into the outline, IvoSmile replaces the user’s maxillary teeth with two possible sets of Ivoclar teeth that can be selected. Additionally, users can activate a slider to adjust their tooth shade. Pressing the pause button freezes the frame so that the image can be captured and shared. The application is easy to use and, for a demo deployment, is remarkably accurate and robust in its AR capabilities. Ultimately, IvoSmile for iPhone is a novelty, albeit one that succinctly demonstrates the commitment to AR that Ivoclar Vivadent has made and generates excitement for the potential of the subscription-based iPad version.

— Alexander Lee, DMD

Would you like to write about technology?

Dentists interested in contributing to this section should contact Andrea LaMattina, CDE, at andrea.lamattina@cda.org.
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