Objective: Scientific papers and books on digital dentistry are in vogue. In most cases, these publications focus clearly on the – undoubted – potentials and possibilities offered by digitalization. The fact that digital dentistry necessarily entails risks and ethical challenges, by contrast, is rarely discussed. This paper aims to complement the discourse on digitalization in dentistry by analyzing precisely these challenges. Method and materials: The study is based on an analysis of international publications and specialist writings on digitalization and its applications in the fields of dentistry and medicine, as well as on the analysis of specific contributions from the disciplines of medical ethics and medical law, and from the public media. Results: The paper identifies and discusses eight core challenges: (1) big data (“digital double” and falsification in dentistry), (2) the dental practitioner-patient relationship, (3) digital literacy, (4) the assumption of responsibility in complex systems, (5) accompanying changes in the dental professions, (6) cost trap and risks of overtreatment in dentistry, (7) consumption spiral and ecologic footprint, and (8) clinical evidence in dental treatments. In addition, a catalog of criteria for assessing the effects of digitalization in dentistry is developed. Conclusion: It is crucial to closely monitor both the potentials and the challenges posed by digitalization in dentistry. Ultimately, it is only those problems that are identified as such that can be resolved and only those technologies that are accepted by dentists, patients, and society that will prevail in the long term. (Quintessence Int 2019;50:830–838; doi: 10.3290/j.qi.a43151)

Key words: big data, clinical evidence, diffusion of responsibility, digital literacy, overtreatment

The digital revolution has led to a situation whereby large sections of society are in a state of transformation – a state that is pointedly described as a new “digital age.” The health sector and health care professions are areas that are noticeably affected. The dental profession, for example, expects digital innovations to expand and facilitate diagnostic and therapeutic possibilities, to improve working conditions, and to create new, professional ways of informing and educating patients. In light of these changes, it comes as no surprise that scientific papers and books on the subject of digital dentistry are booming. In most cases, the focus is clearly on the – undoubted – potentials and possibilities offered by digitalization. In the new media in particular, an unclouded, rosy picture of digital dentistry is drawn, which is primarily oriented towards technical feasibility. Industry-related and technophile articles suggest that “you will get return on your investment in terms of a smoother and more flexible workflow, reduced cost and time, improved accuracy and a high level of predictability. The digital era is simply here to stay, so I suggest you jump on the bandwagon!”

The fact that the digitalization of dentistry – like any revolutionary technical development – necessarily also involves risks and ethical challenges is much less frequently addressed, let alone subjected to critical examination. Yet it is known that a new technology will only be successful in the long term if it enjoys a high and sustained level of social approval. This acceptance is linked in turn to the early identification and iterative management of existing risks and of barriers to acceptance. It is precisely these “blind spots” in digital dentistry that are the subject of the present paper. Eight central challenges posed...
by digitalization in dentistry are identified, correlated, and discussed in depth using concrete examples. It ends with brief conclusions and a catalog of criteria regarding digitalization that aims to serve both the patient and the dental practitioner.

The paper is explicitly not to be understood as a fundamental critique of digital dentistry. Rather, it pursues the aim of supplementing and broadening the discourse on current perspectives on digitalization in dentistry and of responding constructively to existing challenges.

Method and materials

The study is based on an analysis of international publications and specialist writings on digitalization and its applications in the fields of dentistry and medicine, as well as on the analysis of specific contributions from the disciplines of medical ethics, medical law, and from the public media. The methodologic basis for identifying the ethical challenges was the application of central ethical theories, in particular the so-called “four principles” according to Beauchamp and Childress. These are patient autonomy, nonmaleficence (no harm to the patient), beneficence (benefiting the patient), and the principle of justice (eg, fair access to treatment). Aspects of business and environmental ethics were also applied.

In addition, it was indispensable to define the present authors’ concept of digital dentistry prior to the analysis. The term “digital dentistry” refers in the following to any technology used in dentistry that involves digital or computer-controlled components as opposed to purely mechanical or electrical components. This broad definition ranges from the best-known digital applications such as CAD/CAM (computer-aided design/computer-assisted manufacturing) to all other forms of intraoral imaging, and also includes the digital and computer-aided diagnosis of caries, decision-supporting systems, handpieces, (guided) implantology, laser applications, the analysis of occlusion and temporomandibular joint (TMJ), patient education, photography (extraoral and intraoral), practice and patient management, radiography, shade matching (color matching), teledentistry, three-dimensional (3D) printing in dentistry, and digital dentistry in education; this list should be regarded as indicative rather than exhaustive.

Results

In principle, it can be stated that digitalization, like any fundamental technological revolution, creates an ethical “dilemma on two fronts.” First, there is a dilemma with regard to the level of information available (information dimension): It is hardly possible to assess the ethical implications and undesirable side effects of a technology when little is yet known about it and it is barely established. Later, a dilemma arises with regard to controllability (power and control dimension): Once a technology has become widespread and established, it is difficult to control or even reverse it. As a result of these dilemmas, ethics is said to always lag at least one step behind technological development. This applies all the more to technological developments that are not incremental but are — as in the case of digitalization — revolutionary and multidimensional. However, it can be said that digitalization in dentistry has already progressed to such an extent, at least in some areas, that it is possible to identify key challenges associated with it and to illustrate these with examples (Table 1).

Challenge 1: Big data/ data security and data manipulation

Ethical issues related to data protection are of central importance in the digital age, and digitalization in dentistry is no exception. Data security is certainly the best-known and most critically discussed issue and will therefore only be addressed briefly here. The challenge concerns all three major areas of data management: storage, sharing, and use (the latter also including data manipulation). The first difficulty is to preserve the patient’s self-determination regarding information, ie his or her legal and moral right to access his or her own data and to decide on its use. The volume of data generated grows rapidly in the course of digitalization, and much of the data previously stored in analog form (eg, anamnesis surveys and health records) is now kept in a digital format and is therefore much easier to use, extract, transfer, or link. The same applies to data stored on electronic insurance cards and in health apps, etc. The more data generated, the more complex the situation and the greater the corresponding responsibility of the dental practitioner. The same applies to the risk of data being used for purposes other than those for which it was intended, including the classic offence of abuse (eg, for commercial reasons, for risk assessments by health insurance companies).

A number of legal measures for addressing this problem exist. Of these, a few examples should suffice. In many countries, for example, business emails must be archived. When cloud services are used, for example, data privacy guidelines regarding storage space must be observed, which in many places means that patient data may only be stored in cloud...
storage on national territory. The data must be stored in a way that is compatible with the data privacy laws of the respective country.22,29

In addition to these general issues, two critical phenomena shall be examined in more detail: The “digital double” and the falsifiability of dental data.

First, the digital double: This concerns the aggregated and networked data on a patient. More and more individual patient data is being produced in the course of digitalization (health data, data on movement, living and dietary habits, social networking, etc.) and left as traces in the data network. Data of this kind allows conclusions to be drawn about a patient’s health status, habits, and social environment. This aggregated data can be used with growing precision by increasingly powerful algorithms for partially obscure goals (eg, correlation of dental parameters with mobility data, consumption habits, risky behavior, etc). The result is the creation of a “digital double”, ie, a digital alter ego characterized by more data than the person in question knows about him or herself.33

Secondly, falsification: In many cases, digital data can be falsified much more easily – and imperceptibly – than analog data.1 Digital dental radiographic images can be cited as an example here: Even specialists find it difficult to identify manipulated or falsified digital radiographic images. Díaz-Flores-Garcia et al34 investigated this very problem in 2017. Their initial thesis was: “… dental X-ray images may be subject to manipulation with malicious intent using easily accessible computer software.” They thus sought to evaluate a dental practitioner’s ability to identify a manipulated dental radiograph compared with the original. The results were alarming: The participating dental practitioners were correct in identifying the manipulated image in 56% of cases, which was only 6% higher than by chance.34 Visser and Kruger had previously come to even less favorable results.35 In fact, the problem has been under discussion for several years.36 Neuberger and Frandzel37 ironically wrote of “computer-enhanced dentistry” in this context.

**Challenge 2: Dental practitioner-patient relationship**

There are also challenges to the relationship between the dental practitioner and the patient. The role of the dental practitioner has changed under the impact of digitalization: The traditional, direct two-way relationship has become more indirect as a result of the integration of technical systems into patient treatment.38-41

Firstly, the dental practitioner has access to an increased amount of data and information about the patient. More and more individual patient data is being produced in the course of digitalization (health data, data on movement, living and dietary habits, social networking, etc) and left as traces in the data network. Data of this kind allows conclusions to be drawn about a patient’s health status, habits, and social environment. This aggregated data can be used with growing precision by increasingly powerful algorithms for partially obscure goals (eg, correlation of dental parameters with mobility data, consumption habits, risky behavior, etc). The result is the creation of a “digital double”, ie, a digital alter ego characterized by more data than the person in question knows about him or herself.33

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Firstly, the dental practitioner has access to an increased amount of data and information about the patient. This makes it harder for the clinician to treat the patient as having sovereignty over his or her data (see also Challenge 1).

Secondly, digitalization is often accompanied by a reduction of (direct) dental actions on patients: Where, for example, the dental practitioner used to have to make an impression of the patient’s teeth and thus interact physically with him or her, a scanner can now fulfil this purpose.
Thirdly, “expert systems” and robotic systems unquestionably also have an influence on the relationship between dental practitioner and patient. Decision-supporting systems, for example, pose an increasing challenge to the individual clinician’s decision-making competence. The more these aids (eg, treatment support systems) become routine, the more difficult it is for dental practitioners to act against the treatment proposed by the system. In these cases, a clinician must be able to explain to the patient why he or she did not follow the system’s suggestion. This may have forensic implications, for example if an accusation of inappropriate treatment is made at a later date and the clinician’s decision is then questioned.

The relationship between dental practitioner and patient is also changing due to another characteristic of digitalization: Information on the subject of dentistry is available on the internet from a wide variety of providers with different interests, be it in the form of advertisements by dentists for specific offers and services, tools for self-diagnosis from often obscure authors, or health apps whose quality and validity is often unverified. The latter services in particular can lead to misinformation on the part of the patient or even awaken false expectations that the clinician cannot fulfill (see also Challenge 3).

But digitalization also offers opportunities for the relationship between dental practitioner and patient. Here, too, examples should be mentioned briefly: Decision-supporting systems may help inexperienced practitioners to make fewer false judgments. Besides, certain digitalization services (eg, electronic patient files) relieve dental practitioners of some routine work, thereby enabling them to concentrate more on the patient. Further digitalization services (eg, teledentistry) may increase fairness of care by facilitating access to dental advice and care, thereby making a contribution to justice. Last but not least, digitalization on the internet leads to a democratization of knowledge and to patient empowerment, providing of course, that the right (reputable and informative) websites are consulted.

**Challenge 3: Digital literacy**

Every technical system is only as good as its user. Digital technology in particular, which is subject to constant updates and changes, requires an extensive and continuous willingness on the part of the user to learn.

Problems arise when the dental practitioner has inadequate mastery of a new technology. Pasricha recently referred to this point by stating: “Some clinicians will purchase a new technology, yet never read the owner’s manual or seek advanced training on how to operate the technology efficiently, often leading to high failure and abandonment.” Bhambhani et al, Vandenberghe, and van der Zande et al came to similar conclusions, with the latter distinguishing between “early adopters,” “late adopters,” and “non-adopters” of digital technology. Where digital competence is lacking in a health context, it is not only the use of technology that is inefficient. Rather, the patient to whom the technology is applied can also be harmed (see also Challenge 4).

But the digital literacy of the patient also poses an important challenge: Every digital dental intervention must be preceded by informed consent from the patient as an expression of patient autonomy. True informed consent can only be given, however, if the patient fully understands the information about the technology to be applied and if he or she can actually assess the implications of the decision being made. This may not be a problem for patients who are at ease with technology. But those who have little technical affinity may find it much more difficult – or may simply rely on the clinician’s recommendation; in this case, the desired “informed decision” supposedly made by the patient then actually becomes a decision made by an expert.

Certainly, aids are available in these situations. Technically complex facts can thus be optically processed by means of digital visualization in order to make them comprehensible to the patient. There is also an increasing use of gamification. This entails the application of elements and processes typical of games in order to teach the patient technical facts in a playful way. The problem here is that visualization and gamification are again applications of digital technology to which patients must be open. Patients with an affinity for technology will be receptive to such practices, while those with an aversion to technology may not be – and yet they are the very ones who are likely to need such aids.

It follows from the above that both practitioners and patients must be able to cope with digitalization and digital technology, whether as users or as recipients of digital services. In either case, digitalization calls for digital literacy.

**Challenge 4: Assuming responsibility when using complex technical systems**

Human action is becoming more and more complex due to the use of technology. In the case of digital technical systems, many people are involved in the development, operationalization, and application of the technology.

As long as a system works smoothly and without errors, there is no reason for complaint. If a claim is made in the case...
of an error, however, the question arises as to who should be held responsible. Is the fault with the developer, the instructor, or the user of the technical system? In complex human-machine systems involving many parties, it is becoming increasingly difficult to attribute responsibility for an action to an individual. These scenarios are referred to in medicine as a "diffusion of responsibility."

Another problem with complex technical systems is that the legal and ethical evaluation of errors can break down. If, for example, a dental technology (eg, a decision-supporting system or a CAD/CAM system) was already set up incorrectly on delivery and the dental practitioner achieves inadequate results or harms his patient when applying it, the clinician is the final legal authority responsible. In other words, he or she will usually be held legally liable for the inadequate end result. Morally, however, the dental practitioner concerned is only one of many acting parties and decision-making bodies in the system. If the technology was delivered to him in faulty condition (eg, computational fallacy) and the clinician did not commit any operating error or lack technical literacy (see also Challenge 3), he may be morally more of a victim than a perpetrator.

It follows from what has been said that dental practitioners should see themselves as critical companions to any technical support.

**Challenge 5: Changes in the professional profile and self-image of dental practitioners and dental technicians**

Another problem is the fear that the new digital possibilities will lead to fundamental changes in the occupational profile, the public perception, and the self-image of dental practitioners.

Digital dentistry has certainly revolutionized the situation for dental practices and laboratories; in this section the topics of responsibility and justice are touched upon. In Germany, for example, the number of small dental laboratories has been declining for many years, while that of large laboratories has risen by 30% since 2011. Today, the 10% of laboratories with an annual turnover of more than 1 million euros generate approximately 50% of the industry’s turnover. The size of dental practices has also been increasing gradually for several years.

A much-quoted statement is, for instance, that CAD/CAM technology and dental chairside systems are leading to job reductions in dental laboratories. The outsourcing of sub-areas is also described as a consequence of digitalization. There is no doubt that the professional requirements and required professional profiles in the dental professions in particular are currently undergoing change. But these obvious changes also offer opportunities: specialized dental technicians can develop into “CAD/CAM designers” and “dental engineers,” as Eggert and Kordass put it. Both dental practitioners and dental technicians but will have to adapt to changed equipment and workflow practices as well as to an increased (lifelong) need for further training, and furthermore to continue adapting their own know-how (see Challenge 3).

**Challenge 6: Cost trap/ overtreatment/ shift of standards**

Major investments in the digitalization of a practice subsequently require the high-frequency use of the new technology in order to recoup the costs incurred – an aspect that is also referred to as the “amortization trap.”

The perceived need for amortization in turn increases the risk of overdiagnosis and overtreatment, meaning that a medical indication for the use of a technological aid may be overused. Overdiagnosis and overtreatment harm the patient medically and the insured community financially, and therefore constitute a significant ethical issue.

In addition, constant technical upgrading poses the risk of a “shift of standards,” meaning that certain technical processes are used only because they are available, even if they do not promise any additional benefit (see also Challenge 7). Computer-navigated implantation based on cone beam computed tomography (CBCT) data may serve as an example. The mere fact that such computer-navigated implantation is possible and available should not make it a factual necessity. Its use is only justified in the case of a genuine medical indication. Experience shows, however, that technologies of this kind are perceived as the new standard once they have become established to a certain degree. They thus effectively shift the previous standard regardless of whether this benefits the individual patient or not (see also Challenge 2). It is sometimes argued in these cases that a new technology of this kind is used to secure legal protection, ie, its use is justified because it is available and represents a means of increasing patient safety. In these cases, there is a risk of forensically motivated overtreatment.

Finally, digital technologies may produce diagnostic findings with greater accuracy and detail than primarily intended, including random findings. Here, too, ethical questions arise as to how these findings should be dealt with, how the dental patient’s right to non-knowledge can be guaranteed, and how it can be ensured that such random findings do not lead to overtreatment.
All the above examples show the scale of the challenge of weighing technical possibilities against ethical imperatives. Important clinical-normative criteria for this assessment are medical reasonableness, patient welfare, and economic viability.

**Challenge 7: Consumption spiral/ecologic footprint of (medical) technology/“digital sufficiency”**

Digital technologies are generally said to be highly efficient. Proponents of digitalization, in particular, often argue that it offers potential savings, both in terms of time spent and long-term costs.

However, practical experience shows that the constant increase in “efficiency potentials” leads to ever more new devices, further developments of existing systems, or regular updates. These drive costs upwards while also triggering new growth. As a consequence, both effects cancel out the savings potential initially predicted (and hoped for). In this respect, it does not seem realistic to see digitalization as a tool for cost reduction. On the contrary, demand is increasing (a fact that is also referred to as the “consumption spiral”) due to rising efficiency potentials, which refers to the question of the fair distribution of the funds available in the health care system.

This also addresses a second normative problem: the ecologic footprint of digital technology.\(^{18,19}\) Although many hopes are pinned on digitalization, the sustainability aspect is rarely taken into account, especially in the case of digital innovations. Rather, the extremely high pace of innovation cycles involves the release of more and more devices and infrastructures with corresponding disposal requirements – this also applies to the increasingly technological healthcare system and thus to dentistry.

This situation has given rise to recent demands regarding digitalization.\(^{45}\) Prudent use and adequate international concepts for ecologic disposal – in short: a creative “digital policy” – is called for in order to prevent digital scrap from going “through the roof.” “Digital sufficiency” is already being propagated in some places as a new guiding principle for sustainable digitalization,\(^{46}\) true to the motto: as many digital devices and as much networking as necessary, but as little as possible (see also Challenge 6).

**Challenge 8: (Lack of) clinical evidence**

The market launch and success of new digital technologies is often independent of scientific evidence: Despite recognizable efforts,\(^{67-70}\) there is a lack of clinical studies in many cases. Digitalization in implantology is a good example of this, as recent papers by Hong and Oh\(^{71}\) and Colombo et al\(^{72}\) demonstrate. Both papers summarize the existing evidence gaps or “evidence traps.” Hong and Oh\(^{71}\) stated “With the development of new technologies in three-dimension and CAD/CAM, customized implants can be used as an alternative to conventional implant designs. However, there are limitations due to the lack of long-term studies or clinical studies. A long-term clinical trial and a more predictive study are needed.” Colombo et al\(^{72}\) summarize “Within the limitation of this review, based on only two RCTs, the only evidence was that implant survival rate and effectiveness are similar for conventional and digital implant placement procedures. [...] scientific research should focus more in identifying which clinical situations can get greatest benefits from implant-guided surgery. This should be done with research protocols such as RCT that assess comprehensively the advantages and disadvantages of fully digital surgical protocols.”

However, even the conduct and publication of clinical studies on new dental technologies are no guarantee that the results will be useful: A certain technology or technical system has often already been replaced by a follow-up system before studies have had time to gather good evidence on it. This is due to considerable competitive pressure from manufacturers as well as to the increasingly rapid development and renewal cycles to which modern technical products are exposed (see also Challenge 7). It is important to bring the developers and the directors of studies together. Without concerted action on the one hand and broad financial support for clinical trials on the other, the situation regarding evidence will hardly improve in the long term.

**Discussion: Assessment criteria of digital dentistry**

The digitalization of dentistry can, and should, neither be stopped nor “turned back”; the actual task of the dental profession is rather to shape digitalization responsibly and to respond constructively to existing challenges.

Above all, it is important to note that digital dentistry is not an end in itself. Rather it must be measured by its impact on the patient, on the treatment team, and on the dental practitioner-patient relationship.\(^{73}\)

Dentistry should first and foremost serve the patient – this is the core of the dental treatment mandate. For this reason, the most important focus is on the patient-related effects of digitalization. Digitalization can potentially serve the patient in different ways, eg, by improving the quality of diagnosis and/or
therapy, by expanding existing diagnostic or therapeutic options, by making treatment safer, or by reducing the costs incurred by the patient or insured person, to name just a few examples.

The following are the assessment criteria for digital dentistry from the patient’s point of view:
- Qualitative improvement of dental diagnostics and/or therapy?
- Expansion of the diagnostic-therapeutic spectrum?
- Increasing treatment comfort?
- Shortening the duration and/or frequency of treatment?
- Increasing patient safety?
- Strengthening patient autonomy?
- Improving access to dental care?
- Cost reduction?

Digitalization in dentistry should have a positive impact on the dental practitioner and his or her team by supporting them in their work – whether this be technically in the work process or in the sense of a decision-making aid (eg, for young and insecure dental practitioners), by relieving the team of work or other tasks or by opening up new scope for action. The latter can also mean economic room for maneuver, as long as this is not at the expense of the quality of care and does not lead to overdiagnosis or overtreatment.

The following are the assessment criteria for digital dentistry from the dental practitioner’s point of view:
- Support in the work process (eg, technical support, decision support)?
- Elimination of work steps/creation of free spaces (technical, temporal)?
- Increasing the scope for action (technical, economic – if not at the expense of third parties)?
- Increasing the attractiveness of the professional activity (if not at the expense of third parties)?

The effect of digital dentistry can also be seen directly in the dental practitioner-patient relationship. Positive effects can be identified, eg, in the form of qualitatively improved communication (eg, through additional explanatory digital visualization of optional treatments), and quantitatively improved communication (eg, by saving time thanks to digitalization and then using this time for practitioner-patient communication). Positive effects on patient education also have an impact here. They ultimately lead to a reduction in the classic asymmetry between the dental practitioner as a medical expert and the patient as a medical layman: The better informed a patient is and the more self-determined he or she can be when making decisions, the more likely it is that the ideal balance of dental practitioner-patient interaction – so-called shared decision making – can be achieved.

The following are the assessment criteria of digital dentistry with regard to the dental practitioner-patient relationship:
- Improved quality of communication (eg, through visualization of optional treatments)?
- More intensive communication (eg, more time spent on patient education)?
- Improved patient information?
- Reduction of (knowledge) asymmetry (patient empowerment)?

**Conclusion**

It follows from the above that there are clear criteria for assessing the impact of digitalization in dentistry. They should be used as a benchmark for the evaluation of digital technology.

In principle, as much attention should be paid to the challenges and pitfalls of digitalization as to its potentials. In addition, attention should be paid to the success parameters. However, dental practitioners – and health professionals in general – must not be left alone with this demanding task. Adequate management of the digital revolution, as well as the promotion of digital literacy, is a task for society as a whole, including policy-makers. This makes it all the more important for dental practitioners to develop a specific awareness and a keen sense of the digital challenges in their specific domain. Ultimately, it is only those problems that are identified as such that can be resolved, and only those technologies that are accepted by dental practitioners, patients, and society that will survive in the long term. ■
References


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