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Editors

Digitization in Dentistry

Clinical Applications

Springer

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ISBN 978-3-030-65168-8 ISBN 978-3-030-65169-5 (eBook)
https://doi.org/10.1007/978-3-030-65169-5

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Foreword

We are in the digital age, and apparently we have been there since the mid-1970s according to the experts in that field. I graduated from dental school in 1970, and I can assure you that our education and experiences were entirely analog. Our pre-clinical laboratory was equipped with belt-driven handpieces, and we were just introduced to air-driven "high-speed" handpieces for patient care shortly thereafter. Our patient charts consisted of various sizes and colors of paper with (mostly) legible variations of written words, along with sometimes not fully processed radiographic films, some of which had come loose from their cardboard mountings. Our patient communication was either face-to-face, a hand-delivered letter, or a telephone call. There usually was no reliable way to leave a message since answering machines were seldom available or reliable. Our oral hygiene instructions consisted of the patient, sitting in our chair, holding a large mirror in one hand while we showed them how and where to brush with their other hand (the concept of flossing was coming in a few years). They dutifully followed our promptings, in between their drooling and awkwardness; and then they were sent home to try and comply. As a student, our only clue as to some form of digital information was large green bar pages and somewhat washed-out type showing our clinical progress. Those pages were somehow produced from our carbon-copied coupons that were signed off by an instructor when we completed the procedure. That transformation was mysterious, and I can only picture a clerk sitting at a console, inputting that information into an expensive mass of whirling discs and flashing lights, which then spit out the green bar paper.

My first several years in practice during the 1970s were equally analog, although we did produce some simple bulky videotapes about home care that we could play-back for the patient, followed by some beautiful photographs of a sample of our restorative dentistry. Of course, the final single photo was the result of perhaps an entire roll of film. Our radiographs were still being processed in the darkroom with chemicals of questionable safety, and our diagnostic methods were based on our observations and semi-accurate measurements on plaster models. Our treatment planning used wax to approximate a recontoured tooth surface or to simulate restoring the space of a missing tooth.

Fast forward to the present day—dentistry and digitization have a happy relationship. The bits and bytes of our digitized dental information allow us easy storage and availability. It is now such a pleasure to record our examination findings: such items as periodontal data, hard and soft tissue images, pulp vitality tests, and radiographs are all instantly searchable and then displayed in organized areas of our computer's monitor. Gone are the days of trying to ensure the date and accurate number and of a pocket depth, our only remembering a possible enamel crack, or looking at a poorly developed radiograph.

In this book, you will read about the aspects of digitization in dentistry. Using the quality and detail of digitized examination categories, we can more easily decide on a diagnosis and then present treatment plan options to our patients. One example is our ability to use three-dimensional radiograph imaging to discover pathology as well as to analyze the site of an implant fixture placement. Another significant development is the digital impression. In the past, you waited several minutes while your less than relaxed patient tries to tolerate an awkward tray filled with runny material, with you both hoping for a usable impression. Now, in a few seconds, you can quickly analyze an optical impression with its remarkable detail, and your patient is comfortable. Dental surgical procedures, endodontic, orthodontic, periodontic, and restorative procedures all have digital components to aid in the delivery of those therapies. Esthetic procedures can be planned using digital aides on an image of the patient's own teeth, as well as capturing the various contours and shading to produce excellent and satisfying restorative results. Occlusion and temporomandibular joint function can be digitally analyzed, and then tooth surface modification and muscular therapy can be planned and further studied for stability.

Our digital instrumentation continues to improve and advance. Clearly computers are the primary example with increased speed, storage, touch screens, and wireless technology. Indeed, all our data can be accessed that information can be quickly, securely, and easily shared. Our patients could download their records, treatment recommendations, and our instructions; moreover, specialists can understand our referrals. Various other devices are enhanced with digital technology: measurement of endodontic canal lengths is very accurate, and dental lasers are calibrated and their emission energy is precisely controlled.

As in any book, the chapters and their authors have labored to produce the most current information available. However, the development, engineering, design, and manufacture of digital products and services will add to what we know and what we use. For example, three-dimensional non-radiologic imaging using lasers is being studied, and research into nanotechnology will certainly improve our dental materials as well as the pharmacological components of our medications. I can imagine having robotic assistance for some dental surgical procedures, such as gingival grafting or endodontic canal shaping. Moreover, I can dream about using virtual reality in our treatment proposals for esthetic procedures, where the patient actually "sees" the new smile before we proceed. In other words, this book is not the final version of our knowledge, but it is comprehensive for the present.

Looking back over my 50 years in dentistry, I know that our personal touch and communication still is relevant. Digitization has and will continue to aid us in delivering excellent dental care, enhancing our knowledge and experiences. This book will give you that information that will help you become a better dentist. Enjoy!

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Preface

Dentists with decades of experience can clearly look back at the advances in dentistry, since the turn of the millennium, and state that the dental profession has experienced a tremendous amount of technological growth in the digital era. Digital dentistry could be defined as any dental technology or device that comes with digital or computer-controlled components in contrast to mechanical or electrical alone. This broad definition can range from the most common area of digital dentistry—CAD/CAM (computer-aided design/computer-aided manufacturing)—to the new treatment protocols that challenged the traditional methods like the invention of the turbine handpiece and dental implants.

The majority of the areas of dentistry (not exhaustive) which incorporate some type of digital components are as follows: caries diagnosis; CAD-CAM; Computer-aided implant dentistry—including design and fabrication of surgical guides; Digital radiography—intraoral and extraoral, including cone beam computed tomography (CBCT); Lasers; Occlusion and TMJ analysis and diagnosis; Digital Smile Designing; and Shade Matching. In order to be fully advantageous, digital dentistry should include improved efficiency (both cost and time), improved accuracy when compared to traditional methods, and a high level of predictability of positive outcomes. Digital intraoral impressions, digitally fabricated dentures, use of AI, storage of patient data, and the virtual patient are no longer fiction, but, in fact, is now a reality.

This new discipline of digital dentistry is now integrated in educational curriculum in dental schools and in routine clinical practice. Therefore, this comprehensive textbook on *Digitalization in Dentistry* details the digital technology available and describes its indications, contraindications, advantages, disadvantages, limitations, and clinical applications in all aspects of dentistry. The main focus of this textbook is the practical and clinical application of digital technology covering all aspects of dentistry. Available technologies, equipment, and devices are discussed in detail and explained on how they are incorporated in routine clinical practice.

The target audience for this book is a broad group of professionals and includes dental students, general dental practitioners, and specialists of all the dental disciplines. It may also be useful for dental technicians, dental assistants, dental radiographers, and hygienists interested in recent digital advances in the dental field. We hope that the reader will gain a comprehensive understanding of digital applications in dentistry. However, technology changes rapidly, and although every attempt has been made to discuss both the available and the developing technologies expected to be on the market in the future, the scope and list of areas are ever evolving.

There are many other areas of digital dentistry available, and many more are further being researched. Digital dentistry, when properly implemented and fully educated, can bring increased joy in practicing dentistry, and better care for the patients can be delivered.

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Acknowledgments

We would like to start by thanking and acknowledging the contributors to this book who dedicated their expertise, time, and talents to this project. Without their support, this project would not have been successful. Thank you for your hard work and patience.

Working with a talented, patient, and highly professional team at Springer has been an enriching experience. Some of the many people that we'd like to express our gratitude to include:

Alison Wolf

Niveka Somasundaram

And to the many more who helped those named above we extend a heartfelt *"Thank You"!*

We would also like to thank our parents, families, and friends, near and far, who supported us patiently throughout the many hours spent working on this.

We would also like to state that the Editors and authors have made every effort to obtain permission from copyright holders to reproduce material in this book and to acknowledge these sources correctly. However, any omissions brought to our attention are unintentional and will be remedied in future editions.

Contents

1 Artificial Intelligence and Big Data in Dentistry

Priyanka Jain and Catherine Wynne

1.1 Introduction

The profession of dentistry continuously demonstrates innovation and improvement on many fronts such as clinical applications, research, training, and education. This new era includes the broad array of technologies that brings the communication, documentation, manufacture, and delivery of dental therapy under the umbrella of computer-based algorithms. Digital dentistry can be defined as the use of any dental-related technology or device that is built-in digital or computer-controlled elements rather than operated electrically and/or mechanically alone.

Historically, digital advances have three foci: CAD/CAM systems, imaging, and practice/patient management systems. CEREC™, the first commercially available in-office CAD/CAM system made possible, the delivery of same-day restorations. Early drivers in imaging include both the intraoral imaging systems integral to the CERECTM system and evolutions in digital radiography. First introduced in the late 1980s, digital radiography has transformed the dental field, enhancing image quality, evolving from phosphor plates to solid-state detectors, cone beam computed tomography (CBCT), and new generations of digital impression taken with intraoral scanners. The development of cone beam computed tomography (CBCT) heralded a second wave of excitement as three-dimensional images of the craniofacial region offered new advantages in diagnostics and therapy. When iterative improvements in hardware, software, and materials merged in the early 2000s, new accomplishments in clinical dentistry were realized.

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P. Jain, M. Gupta (eds.), *Digitization in Dentistry*,
https://doi.org/10.1007/978-3-030-65169-5_1

Practice management software makes possible capturing patient demographics, scheduling appointments, and generating reports. In parallel, electronic patient records, a digital version of patients' clinical information, motivated changes in tracking patients' health, facilitating quality of care assessments, and proved a resource for research, including evaluation of efficiency and efficacy of clinical procedures. In parallel, other technologies influenced and enabled innovations in digital dentistry, often at a remarkable pace. While not a comprehensive list, these technologies undoubtedly include sensor miniaturization, artificial intelligence, augmented and virtual reality, robotics, 3D printing, telehealth, Big Data, internet of things, nanotechnology, quantum computing, biomedical engineering, cost of data storage, connectivity, and others.

This chapter is an introduction to this book. As stated above, the list of digital technologies is not exhaustive, and every attempt has been made to include the most recent innovations to keep the reader up to date. However, technologies change and new innovations may already be on the market by the time this book goes into printing.

The chapter will review how digital dentistry has influenced different aspects of dentistry in brief. A major part of this introductory chapter will deal with the scope of Big Data and Artificial Intelligence, the two most recent advancements in digital dentistry.

While the scope of digital systems is immense, those discussed in this book focus primarily on those that have implications and opportunities for developments and innovations in clinical dentistry. Digitization, being so significant in the dental practice, needs to be understood well. The book serves as a contemporary reference considering the pros and cons of various technological progresses. The impact of digital technology in dentistry is immense, hence for ease its influence is considered under sections—the clinical aspect, laboratory procedures, training of students, patient motivation, practice management, and dental research (Table 1.1).

1.2 Recent Trends in Digitization

The digital transformation in dental medicine is recognized as one of the major innovation of the twenty-first century. The implementation of mobile technologies into the medical sector is fundamentally altering the ways in which healthcare is perceived, delivered, and consumed. The most recent trends and innovations of this new digital era, with potential to influence the direction of dentistry in the future, are: *(1) rapid prototyping (RP), (2) augmented and virtual reality (AR/VR), (3) artificial intelligence (AI) and machine learning (ML) for diagnostic analysis, (4) Big Data and analytics (personalized (dental) medicine and linkage of health data, mHealth, teledentistry, and development of electronic health records).*

The advancement and increased use of Internet and Communication Technologies (ICT), the rise of Big Data and algorithmic analysis, and the origin of the Internet of Things (IOT) are a multitude of interconnected innovations that are having a significant impact on today's society and affecting almost all spheres of our lives,

Table 1.1 Applications of digitization in dentistry

Aspect	
Role of digitization for training and research	Audiovisual aids Virtual simulators for surgical training Haptics Virtual dental patient (PerioSlim™) Digital material testing
Role of digitization in diagnosis and treatment planning	Digital radiography, CBCT Radiovisiography (RVG) Dental photography Diagnosing occlusal errors (T scan) Diagnosing TMJ disorders Big data analytics
Role of digitization in treatment	Digital impressions CAD CAM (restorations, tissue scaffolds, surgical Guides) Digital shade analysis Digital smile design Lasers Virtual articulators Teledentistry Research Robot-assisted treatments
Role of digitization for patient motivation and practice management	Intraoral camera Educational software Digital data (electronic health records, radiographs, Digital photographs, intraoral scans) Patient interactions (consultations, shared decisions, healthy behaviors)
Other activities	Epidemiology research

including medical science [1, 2]. Dentistry, as a branch of medicine, has not remained unaffected by the digital revolution. Research in the dental field on the effect of digitization is focused on both dental clinical practice and research.

Linkages of population health data could prove beneficial for research, such as assisting with the identification of unknown correlations of oral diseases with suspected and new contributing factors and furthering the creation of new treatment concepts [3]. Digital imaging can promote accurate tracking of the distribution and prevalence of oral diseases to improve healthcare service provisions [4]. New possibilities have opened up for automated processing in radiological imaging using artificial intelligence (AI) and machine learning (ML). AI can also be used to enhance the analysis of the relationship between prevention and treatment techniques in the field of oral health [5]. A digital or virtual dental patient, via 3D cone beam computed tomography (CBCT) and 3D-printed models, could be used for precise preoperative clinical assessment and simulation of treatment planning in dental practice [6, 7]. This topic is dealt with in great detail later in the book. With the use of smartphones and wearable technologies, mobile health (mHealth) applications are increasingly gaining popularity and being explored by healthcare providers and companies' provision of healthcare services [8].

It is important to keep in mind that since these technologies are still at the early phases of implementation and trials, technical issues and certain drawbacks might emerge. Basic science, clinical trials, and subsequently derived knowledge for innovative therapy protocols need to be redirected toward patient-centered outcomes, enabling the linkage of oral and general health instead of merely industry-oriented investigations [5]. For example, use of Big Data analytics and its applications and AI must be done systematically according to harmonized and inter-linkable data standards, otherwise issues of data managing and garbage data accumulation might arise [9]. AI for diagnostic purposes is still in the very early phases, and analysis of diverse and huge amounts of EHR (electronic health records) data still remains challenging [10]. In the simulation of a 3D virtual dental patient, dataset superimposition techniques are still in their experimental phase.

It needs to be understood that digital smart data and other technologies will not replace humans providing dental expertise and the capacity for patient empathy. The dental team that controls digital applications remains the key and will continue to play the central role in treating patients. In this context, the latest trend word created is *augmented intelligence*, that is, the meaningful combination of digital applications paired with human qualities and abilities in order to achieve improved dental and oral healthcare ensuring quality of life [11].

1.2.1 Rapid Prototyping (RP)

In dental medicine, several digital workflows for production processing have already been integrated into treatment protocols, especially in the rapidly growing branch of computer-aided design/computer-aided manufacturing (CAD/CAM), and rapid prototyping (RP) [12]. RP is a type of computer-aided manufacturing (CAM) and is one of the components of rapid manufacturing. RP is a technique to quickly and automatically construct three-dimensional (3D) models of a final product or a part of a whole using 3D printers. These 3D physical structures are known as rapid prototypes. RP technique allows visualization and testing of objects [13].

Rapid prototyping may be categorized into *additive method (widely used) and subtractive (less effective).* The additive manufacturing process allows inexpensive production of complex 3D geometries from various materials and involves minimal material wastage [14]. The frequent technologies that are adopted in dental practice are selective laser sintering (SLS), stereolithography, inkjet-based system (3D printers [3DP]), and fused deposition modelling (FDM).

CAD and RP technologies are being used in various fields of medicine and dentistry. They have had a considerable impact especially on the rehabilitation of patients with head and neck defects, in fabrication of implant surgical guides, zirconia prosthesis and molds for metal castings, maxillofacial prosthesis and frameworks for fixed and removable partial dentures, and wax patterns for the dental prosthesis and complete denture.

In dentistry, one of the main difficulties today is the choice of materials. Commercially available materials (wax, plastic, ceramic, metal) commonly used for RP are currently permitted for short to medium-term intraoral retention only and not yet intended for definitive dental reconstructions [15].

RP has the potential for mass production of dental models, and also for the fabrication of implant surgical guides [16]. Production in large quantities at the same time in a reproducible and standardized way is an advantage in reducing the costs. It can also be used in 3D-printed models for dental education based on CBCT or micro CT. An initial study, however, has revealed that 3D-printed dental models can show changes in dimensional accuracy over periods of 4 weeks and longer. Further investigations comparing different 3D printers and material combinations are however still required [17]. The limitations of RP technology include complicated machinery and dependency on expertise to run the machinery during production in addition to the high cost of the tools.

Further research is currently focused on the development of printable materials for dental reconstructions, such as zirconium dioxide (ZrO_2) [18]. This different mode of fabrication of ZrO_2 structures could allow us to realize totally innovative geometries with hollow bodies that might be used, for example, for time-dependent low-dose release of anti-inflammatory agents in implant dentistry [19].

From a futuristic point, synthesis of biomaterials to artificially create lost tooth structures using RP technology could prove to be revolutionary [20]. Instead of using a preformed dental tooth databank, a patient-specific digital dental dataset could be acquired at the time of growth completion and used for future dental reconstructions. Furthermore, the entire tooth can be duplicated to serve as an individualized implant. RP technology can provide customized and tailored solutions to suit the specific needs of each patient. While the future looks promising from a technical and scientific point of view, it is not yet clear how RP and its products will be regulated.

1.2.2 Big Data

Information is the key for better practice and new innovations. The more information we have, the more we can arm and organize ourselves to deliver the best outcomes. Data collection plays an important role in this regard. In today's modern age, we produce and collect data about almost everything in our lives such as social activities, science, work, health etc., and this is increasing at a rapid pace. In a way, we can compare the present situation to a data deluge. The technological advances have helped us in generating more and more data, but we have seemed to reach a level where it has become unmanageable with currently available technologies. However, as the data has been getting bigger, our ability to transform and translate the data has also improved, and allowed us to move from reporting what has happened in the past (data reports or "descriptive analytics") to learning what is going to happen in the future (data science or "predictive analytics") [21].

This has led to the creation of the term "big data" to describe data that is large and unmanageable. In order to meet our present and future social needs, we need to develop new strategies to organize this data and to extract the information contained and transform the raw data into knowledge and derive meaningful information. One such need is healthcare. Like every other industry, healthcare is producing data at a tremendous rate that presents many advantages and challenges at the same time. "Big Data" begins to form when a group of data sets brought together become so large and complex that it begins to challenge contemporary data processing and analytical approaches. More data does not let us see more of the same but it allows us to see better, to see different, and to see something new.

Health data can be gathered from routine care and other sources such as social determinants of health, posts by patients on internet forums, surveys and questionnaires from patient support groups and patient diaries. Big Data collaborations involve interactions between a diverse range of stakeholders with varying analytical, technical, and political capabilities. Medical data has its uses in many areas of applications in healthcare, such as prognostic analysis and predictive modelling, identification of unknown correlations of diseases, clinical decision support, treatment concepts, public health surveys, and population-based clinical research, as well as the evaluation of healthcare systems [22].

Even though a number of definitions exist for Big Data, the most accepted is given by Douglas Laney who observed that (big) data was growing in three different dimensions, namely, volume (the amount of collected data), velocity (the speed of generated data), and variety (the source and type of data) (known as the 3 Vs) [23]. The "big" part of "big data" is indicative of its large volume. In addition to volume, the Big Data description also includes velocity and variety. These three Vs have become the standard definition of Big Data. Another accepted fourth V is "veracity" (the quality of incoming data) [24] (Table 1.2).

Table 1.2 What creates Big Data?

Data accumulation matters (velocity)	Indicates the speed or rate of data collection and making it accessible for further analysis Data accumulates expansively
Data quality matters (veracity)	Indicates the quality, authenticity, "trustworthiness" of data [25]. More data does not always give us more "value" Information from data becomes more valuable when the data is more reliable Data-driven decision-making requires accurate and reliable data
Data size matters (volume)	At its most elementary level, big data is about bringing datasets together There is no critical mass of data alone needed to make it "big."
Data complexity matters (variety)	Variety indicates the different types of organized and unorganized data that any firm or system can collect, such as video, audio files A mix of varying types and sources of data is needed to make it complex and large Data linkages are important

Biomedical Big Data amasses from different sources such as electronic health records, health research, wearable devices, and social media. The delay in reaping the benefits of biomedical Big Data in dentistry is mainly due to the slow adoption of electronic health record systems, unstructured clinical records, tattered communication between data silos, and perceiving oral health as a separate entity from general health. Recent recognition of the complex interaction between oral and general health has acknowledged the power of oral health Big Data on disease prevention and management.

This section will introduce the reader about the basics of Big Data and data analytics in dentistry related to different applications such as population data linkage, personalized medicine and electronic health records (EHRs), and mobile health (mHealth) and teledentistry.

1.2.2.1 Electronic Health Records (EHR) and Data Analytics

The electronic health record is a rich source of data that helps dentists monitor the health data of their patients and promote the sharing of information between various members of the healthcare team. EHRs have introduced many advantages for handling modern healthcare-related data. Dental professionals have access to the medical and dental history of the patient. This enables an improved care coordination and communication among healthcare providers and patients. Healthcare professionals have also found access over web-based and electronic platforms to improve their practices significantly using automatic reminders and prompts regarding follow-ups and appointments, and other periodic checkups. EHR enables faster data retrieval and helps provide access to millions of health-related medical information. EHR is further covered in Chap. 13. Table 1.3 gives its uses in dental practices.

National Institutes of Health (NIH) recently announced the “All of Us” initiative that aims to collect one million or more patients’ data such as EHR, including medical imaging, socio-behavioral, and environmental data over the next few years [26].

Similar to EHR, an electronic dental record (EDR) stores the standard medical, dental, and clinical data gathered from the patients. EHRs, EDRs, personal health record (PHR), medical practice management software (MPM), and many other healthcare data components collectively have the potential to improve the quality, service efficiency, and costs of healthcare. The Big Data in healthcare includes the healthcare payer-provider data (such as EHR, EDR, pharmacy prescription,

Table 1.3 Uses of EHR

Uses of EHR in dental settings
• Maintain patient documentation and records • Integration of digital technologies • Clinical support tools • Identification of gaps in care • Access and storage of digital images • Support for administrative tasks • Evaluation of practice-based treatment outcomes

insurance records) along with the gene expression data and other data acquired from the smart web of Internet of things (IoT). The management and usage of such healthcare data is, however, dependent on information technology.

By analyzing Big Data, dentists can help patients improve health, diagnose the disease at an early stage, and also provide them with personalized dental care. But analyzing huge amounts of patient data manually is impossible. Big Data analytics help in analyzing this data, including personal patient data and demographic data, to identify which oral health problems recur repeatedly, thus helping the dental professionals in diagnosing and treatment planning. Also, by examining the medical and dental records, Big Data analytics can give dentists accurate insights into the oral health problems that are likely to occur in the future. In a nutshell, by analyzing real-time data, Big Data analytics help in revolutionizing the oral health of the population, thereby paving the way to precision medicine. Falling costs (per record) of digital data storage and the spread of low-cost and powerful statistic tools and techniques to extract patterns, correlations and interactions, are also making data analytics more usable and valuable in dental medicine. However, there remains barriers to its universal adoption and integration that still needs to be overcome.

Recent research has focused on the implementation of EHRs both in private practices and in dental education [27–29]. Cederberg and Valenza [28] argue that the use of digital records might compromise the doctor–patient relationship in the future, as easy access to all relevant information through digital means and forced focus on the computer screen could accustom both dentists and students to becoming more detached from patients. Big Data in the field of biomedical research is also useful as researchers analyze a large amount of data obtained from multiple experiments to gain novel insights. However, this poses issues of informed consent for both patients and research participants [30, 31].

Other ethical issues that arise from its use are data security, resulting in a breach of patient privacy and confidentiality [28, 32]. The legal issues surrounding health privacy, for example, sharing of data across national borders, creates hurdles for both individuals trying to access their own personal information as well as for biomedical researchers attempting to establish randomized controlled clinical trials. Therefore, dental biobanks with sensitive patient material, such as saliva, blood, and teeth, must be clarified, as these samples could be used for genetic analysis [33]. Data anonymization is a type of information sanitization where privacy protection is the single most intent. It is the process of either encoding or removing personally identifiable information from datasets. Anonymization methods include encryption, hashing, generalization, and pseudonymization. De-anonymization is the reverse engineering process used to detect the source data. The most common technique of de-anonymization is cross-referencing data from multiple sources [34].

The concept of "blockchain" is also gaining popularity in data sharing. It is a distributed ledger technology implemented in a decentralized manner used to record transactions [35]. Therefore, dentists can store their patients' records on a decentralized ledger, helping them save their money and time in having paper-based records. The records are kept across many computers such that data cannot be changed retroactively without the alteration of all subsequent blocks and collusion with the entire network [36]. Additionally, dentists and patients can reap the advantage of blockchain being “immutable,” helping their records to be secure by offering distributed database, peer-to-peer transmission, transparency with pseudonymity, irreversibility of records, and computational logic [37].

Challenges associated with Big Data should also be considered at the same time, apart from data sharing. Storing large volume of data is one of the main challenges, and an on-site server network can be expensive to scale and difficult to maintain. The data needs to cleansed or scrubbed to ensure the accuracy, correctness, consistency, relevancy, and purity after acquisition. This cleaning process can be manual or automatized. Patients produce a huge volume of data that is not easy to capture with traditional HER format, as it is not easily manageable. It is too difficult to handle Big Data especially when it comes without a perfect data organization. A need to code all the clinically relevant information is required. As a result medical coding systems like International Classification of Diseases (ICD) code sets were developed. However, these come with their own limitations. Studies have observed various physical factors that can lead to altered data quality and misinterpretations from existing medical records [38]. Images often suffer technical barriers that involve multiple types of noise and artefacts. Improper handling of medical images can also cause tampering of images which may lead to delineation of anatomical structures.

1.2.2.2 Personalized Medicine and Data Linkages

Personalized medicine can change how dental research is conducted. Genomic sequencing and recent developments in medical imaging and regenerative technology have redefined personalized medicine to perform patient-specific precision healthcare [39, 40]. An interdisciplinary approach to dental patient sample analysis in which dentists, physicians, and nurses can collaborate to understand the interconnectivity of disease in a cost-effective way can be made possible [41]. Examining large population-based patient groups could detect unidentified correlations of diseases and create prognostic models for new treatment. Linkage of population-based data has changed the way epidemiological surveys in public health are conducted and will play a predominant role in future dental research. The linkage of individual patient data gathered from various sources enables the diagnosis of rare diseases, and completely novel strategies for research [32] helps to identify unknown correlations of diseases, prognostic factors, and newer treatment concepts, and to evaluate healthcare systems [42].

Register-based controlled (clinical) trials (RC(C)T) is a relatively new approach in dental research. These trials can provide comprehensive information on hard-to-reach populations and allow observations with minimal loss to follow-up. However, they require large sample sizes and generate high level of external validity. In the context of data linkage in dental practices and personalized medicine, research has shown that consent might be a significant issue concerning data usage as the patient cannot be completely informed about the ways in which the collected data is/will be used [43]. Data anonymization [44] and patient confidentiality [45] are other issues of data linkage. Therefore, the use of linked biomedical data to support register-based research presents the challenge of disclosing sensitive information about individuals whose consent cannot be easily obtained in retrospect.

Individual dental disciplines (Prosthodontics, Restorative Dentistry, Periodontology, Oral Surgery, and Orthodontics) usually tend to work in isolation in academic dental institutions or large dental service providers. This can result in non-standardized diagnostics within the different departments. An integrated approach with standardized dental diagnostic protocols could enhance better patient flows and reduced overall treatment time and support interdisciplinary linked-therapy planning with improved quality, higher efficiency, and increased patient satisfaction [46]. Additionally, linking this standardized dental diagnostics with biomedical patient-level data could provide the information needed to better understand the epidemiology and etiological pathogenic pathways of oral diseases [47].

The collected data and information of population-based register-based controlled clinical trials RC(C)Ts can also provide an understanding of current and future applications of personalized dental medicine and help to improve prevention and rehabilitation concepts of oral diseases. In the future, private dental professionals together with academic dental institutions will increasingly generate digital data. A major challenge will be the compliance with quality standards in data acquisition, storage, and safe transfer. This will have an impact on the daily routine for the general dental practitioner [46].

1.2.2.3 Mobile Health (mHealth) and Teledentistry

Digital technologies are altering the ways in which healthcare is delivered and consumed. Tele-healthcare enables a convenient way for patients to increase self-care while potentially reducing office visits and travel time [48]. Considering the growing number of the elderly population with reduced mobility and/or nursing homestay, special-care patients, as well as people living in rural areas, these patient groups benefit significantly from teledentistry [49, 50]. Internet is the basis of modern systems of teledentistry, being able to transport large amounts of data. All new systems of teledentistry are internet-based. Changes within the past decade in the speed and method of data transfer have prompted clinicians and information technology experts to re-evaluate teledentistry as a highly valuable healthcare tool.

The practice of medicine using digital mobile devices, known as mHealth or mobile health, pervades different degrees of healthcare by finding ways to utilize mobile technologies for remotely measuring health and delivering healthcare and preventive health services. Newer mHealth technologies with embedded sensors require little attentional effort from the user and allow the unobtrusive collection of objective, high-resolution data on “real-world” health indicators and health behaviors [51, 52].

The capabilities of mHealth have led to the development of personalized healthcare delivery models that shift the responsibility for personal health away from health systems toward the individuals. By allowing individuals to conveniently track and manage everything about their health, from blood pressure to glucose, the mHealth technology encourages individuals to be actively responsible for their own health, helps them understand their health status, and engages them in preventive behaviors while being guided by input from their health professionals. Furthermore, the remote monitoring abilities of mHealth technologies allows the professionals to proactively identify those at risk for an adverse health event and intervene in a timely manner.

The application of mHealth technology is of great relevance to dentistry. Most often, a patient's non-adherence to toothbrushing techniques recommended by dental professionals is misunderstood, forgotten, or even completely ignored [53]. The variety of brushing techniques recommended by dentists and dental associations also adds to the confusion among patients [54]. The gap between quality oral hygiene routines and what is actually practiced by individuals is further increased by the dentist's inability to monitor actual brushing behaviors and good oral hygiene practices at home. Newer mHealth-based technology platforms being developed allow unobtrusive, remote monitoring of toothbrushing behaviors in real-world settings and provide customized, titrated feedback (Fig. 1.1).

The Remote Oral Behaviors Assessment System (ROBAS) utilizes commercially available electronic toothbrushes and/or smart watches as data collection devices and captures key details of toothbrushing behaviors (when used, for how long, pressure applied, dental quadrants covered) in the home setting. The ecologically accurate data is collected and securely transmitted to a cloud server for subsequent analyses by appropriate statistical tools. Such a mHealth platform could serve as the basis of a scalable, interactive ecosystem that passively monitors OHRs, infers and predicts improper OHRs, and delivers engaging and timely personalized feedback to support quality OHRs by individuals [21].

Currently, brushing and flossing behaviors are recorded by measuring traditional oral hygiene indicators (i.e., dental plaque, periodontal inflammation, and caries) during a clinic visit in addition to patient self-reports of their toothbrushing practices. However, they become difficult when involving larger groups or populations, particularly those without regular access to dental services. Low-touch mHealth systems could help clarify the precise relationships between toothbrushing behaviors captured in the home environment and the health outcome (i.e., plaque and dental disease) assessed in the dental setting. By utilizing mHealth's real-time monitoring and feedback capacities, dental professionals would be better armed to stress upon the importance of correct and long-term adherence to oral hygiene practices and understand the determinants/predictors of why individuals do or do not engage in the prescribed oral hygiene practices [21]. Using mHealth systems in combination with oral hygiene practice measurement and feedback devices (i.e., electronic toothbrushes, smartphones) and back-ended by risk prediction and personalized

Fig. 1.1 Smart toothbrush and its working

intervention algorithms, digitally engaged patients would exert more control of their own oral health while providers would be able to provide quality patient-centered and value-based care.

As discussed previously for other Big Data clinical applications, issues of data security, patient anonymity [55, 56] and confidentiality [57] are primary concerns, as networked transfer through unsecure means could enable unwarranted

Table 2.5 Various imaging technologies for pocket depth measurement

Method of imaging	Benefits	Limitations
CBCT	High resolution Low radiation exposure Broad range of applications Popular and widely used in dental care	Ionizing radiation Metallic image artifacts
OCT (optical coherent tomography)	High resolution and tissue contrast Nonionizing	Cannot be used for deep tissue imaging due to scattering of the light waves
Photoacoustic imaging topography	Nonionizing High resolution and tissue contrast Deep tissue imaging	Thick bones can distort signal Poor penetration of gas cavities
MRI	Nonionizing Soft and hard tissue imaging	Long scanning time Only soft tissue imaging with low resolution is possible with conventional MRI Not enough evidence to show if newer generations of MRI can image periodontal pockets

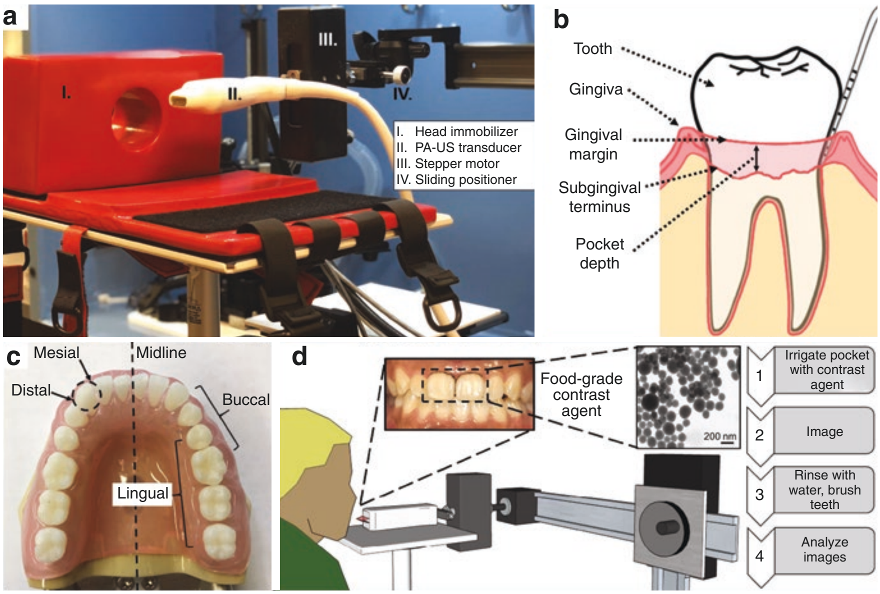


Fig. 2.11 Overview of the imaging setup, periodontal anatomy and workflow. (**a**) The PA-US transducer was connected to a stepper motor for axial scanning and a sliding positioner for lateral control. The head mobilizer rested on a flat surface (**b**) Periodontal anatomical features (**c**) Anatomical terms for reference (**d**) Experimental workflow—A contrast agent was used to irrigate the pocket of the target tooth followed by photoacoustic imaging. The pocket is then rinsed with water and images analyzed to measure pocket depths. (*Courtesy of Dr. Jesse V. Jokerst, Department of NanoEngineering, University of California, San Diego)*

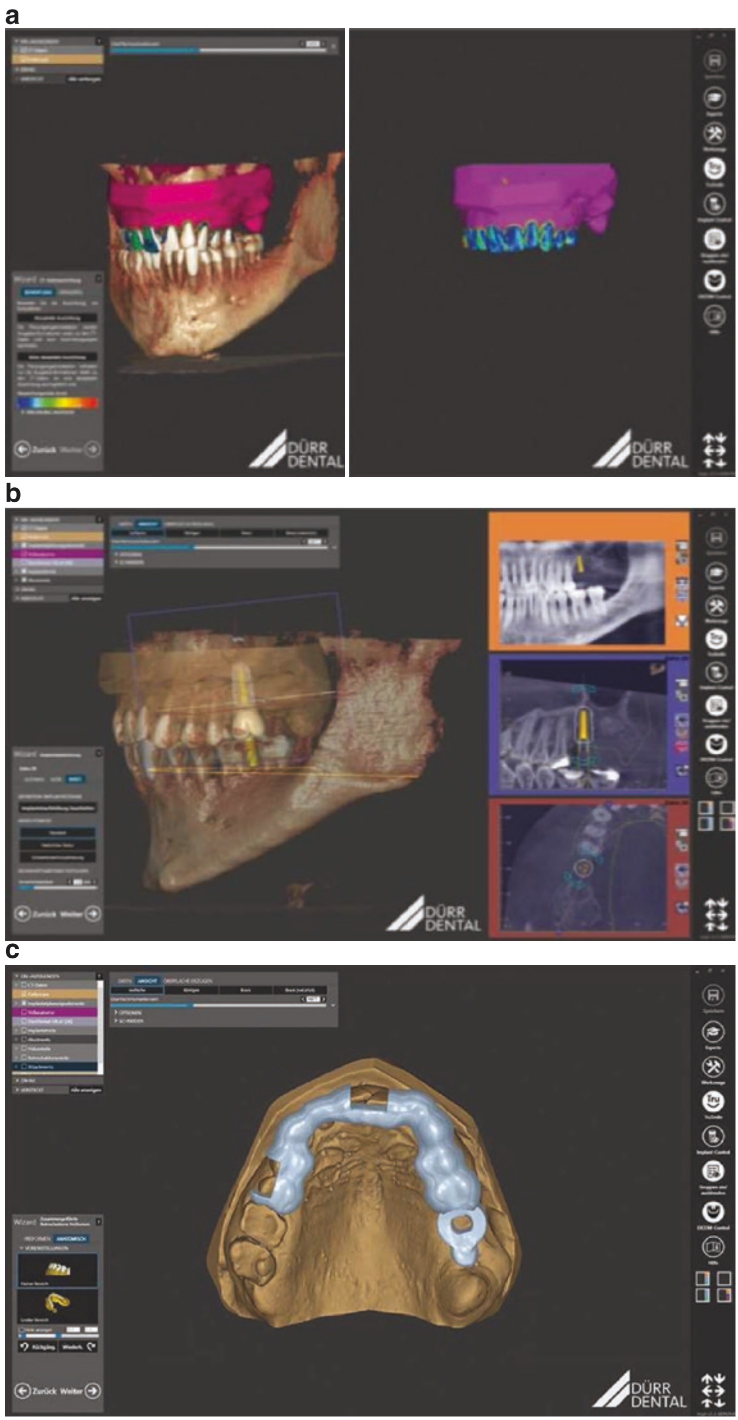


Fig. 2.13 Guided implant planning. (**a**) Automatic expansion of the matching of intraoral impressions and CBCT. (**b**) Intuitive and efficient implant planning. (**c**) User friendly drill template planning *(Courtesy Duerr Vista Soft, Duerr Dental)*

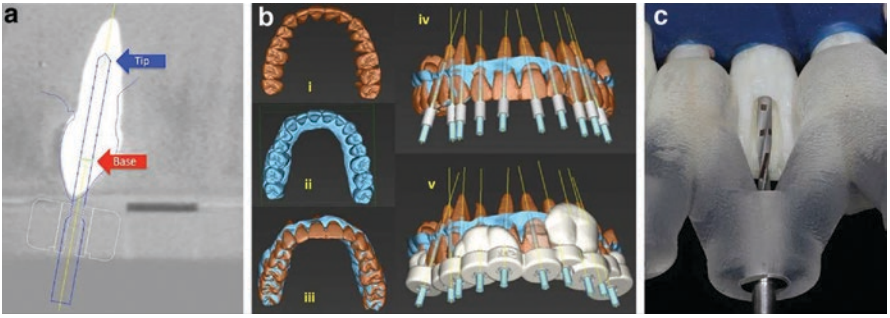


Fig. 4.17 (**a**) The virtual bur is superimposed with the tooth to create straight line access to the apical third of the root canal. The base of the bur (red arrow) and the tip of the bur (blue arrow) can be seen. (**b**) The matching between CBCT and teeth scans, (i) CBCT scan, (ii) teeth scan, (iii) matched scans, (iv) virtual Bur in the matched scan, (v) designed template (sleeves and burs). (**c**) Clinical application, the bur was guided through the sleeve to the apical third of the root canal (*Reproduced with permission from John Wiley & Sons*) [111]

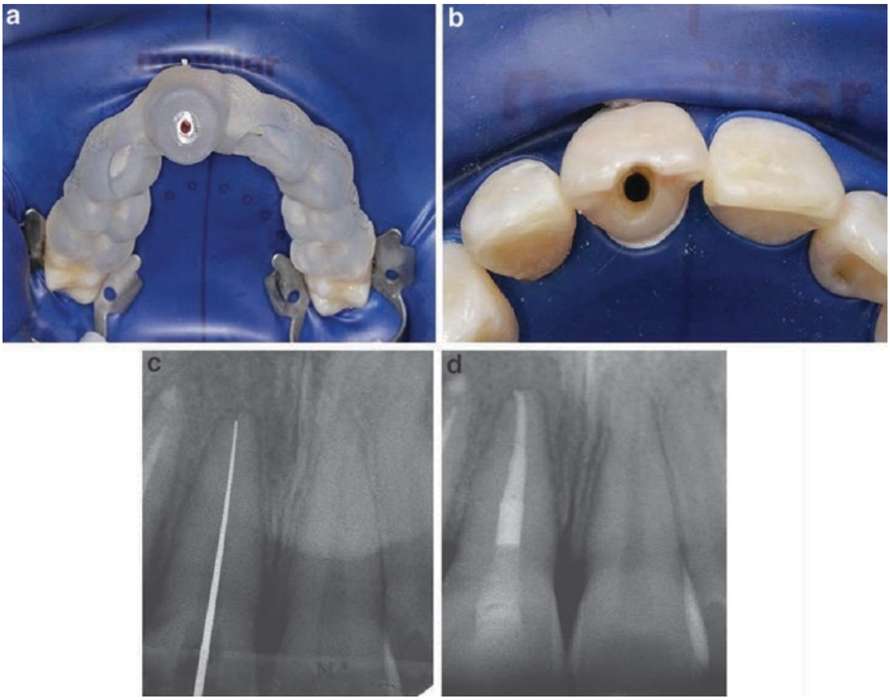


Fig. 4.18 (**a**) Template positioned on the maxillary teeth to check its correct and reproducible fitting. (**b**) View of the endodontic access cavity after root canal location. Control radiograph with silver cone in the root canal. (**c**) Successful instrumentation of the calcified root canal (**d**) Postoperative radiographic examination. (*Reproduced with permission from John Wiley & Sons*) [108]

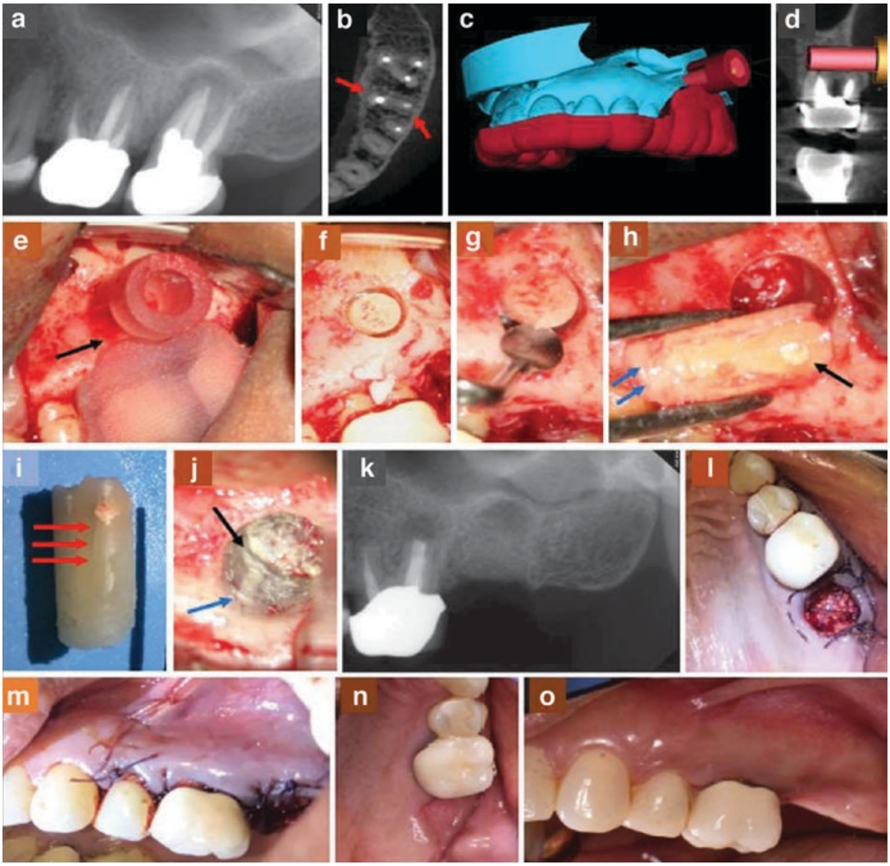


Fig. 4.31 The palatal root of tooth #17. (**a**) Preoperative periapical X-ray shows two sinus tracts (black arrows). (**b**) The gutta-percha cone tracing the distal sinus tract to palatal root of tooth #17. (**c**) 3D surgical guide (3DSG) was fabricated on the digital cast. Note the trephine port that was designed for contralateral occlusal clearance. (**d**) A coronal view of CBCT shows the planned trephine path. (**e**) The trephine path avoids the GPA traced in yellow from the greater palatine foramen running anteriorly. (**f**) 3DSG with custom fit trephine. (**g**) To produce bleeding points, 3DSG with trephine is inserted in port. (**h**) Bleeding points and subsequent incision for mucosal window. (**i**) Mucosal window after trephine osteotomy with core in place. (**j**) Core specimen with palatal cortical bone (black arrow), resected root end, and soft tissue (blue arrows). (**k**) Immediate postoperative radiograph. (**l**) Immediate postoperative image with replanted palatal mucosa. (**m**) One week postoperative. (**n**) Four weeks postoperative. (**o**) Three months postoperative with healed palatal tissue and sinus tracts (*Reproduced with permission from Elsevier Publishing*) [116]. (**Disclaimer**—*"Targeted Endodontic Microsurgery U.S. patent Application No. 16/396,185 was filed April 26, 2018. All rights, title, and interest have been assigned to the Government of the United States. One or more embodiments of the inventions described in these patent applications are described in this textbook chapter. The views expressed are those of the author's and do not reflect the official views or policy of the United States Department of Defense or the Uniformed Services University of the Health Sciences"*)

Fig. 5.12 (**a**) View of peri-implant mucositis on the lower right second molar implant fixture. (**b**) Prior to diode laser use, biofilm and other accretions removed from the implant with hand instruments. View shows diode laser is use to remove the diseased soft tissue, offer bacterial reduction, and provide hemostasis. (**c**) Four month postoperative probing demonstrates healthy tissue and implant stability

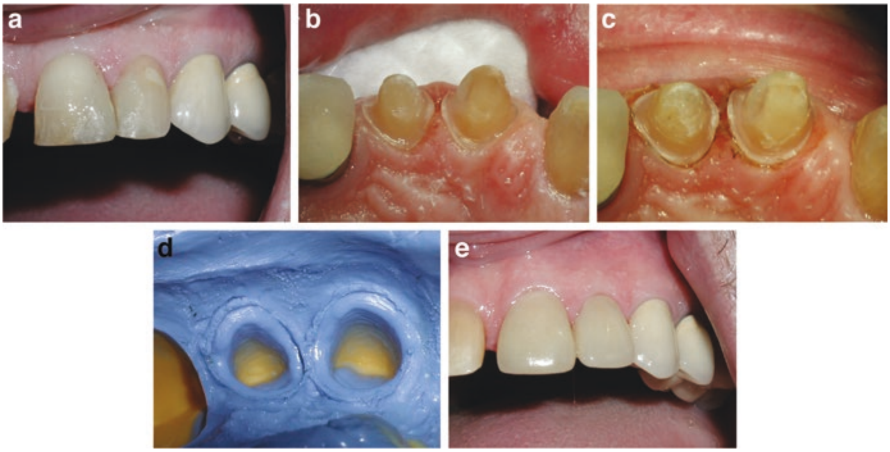


Fig. 5.13 (**a**) Maxillary left central and lateral incisors that will receive full porcelain crown restorations. (**b**) Completed preparations before any gingival tissue manipulation. (**c**) Diode laser used for tissue retraction and hemostasis, immediate postoperative view. Note completely dry field. No conventional retraction cord was used. (**d**) Immediately after laser use, an impression was taken. There is no debris and excellent detail. (**e**) Restorations placed 2 weeks later. The tissue height and tone responded well to the laser tissue retraction

Figure 5.14 shows preoperative gingival enlargement and immediate postoperative tissue removal using diode laser.

Gingivectomy with Er:YAG, Er,Cr:YSGG laser is advised for immunocompromised patients and in the removal of plaque/calculus from root surface with sufficient water cooling [68, 69]. A diode laser can also be used, although hyperplastic tissue can be very challenging to remove with the diode. However, normal tissue can be excised with good results. Fig. 5.15 shows the uncovering of a fully integrated implant fixture, and Fig. 5.16 shows soft tissue gingivectomy for an aesthetic procedure.

Crown lengthening procedures can also be done using a laser. Diode lasers and Nd:YAG have proven useful in removing soft tissue effectively without damage to

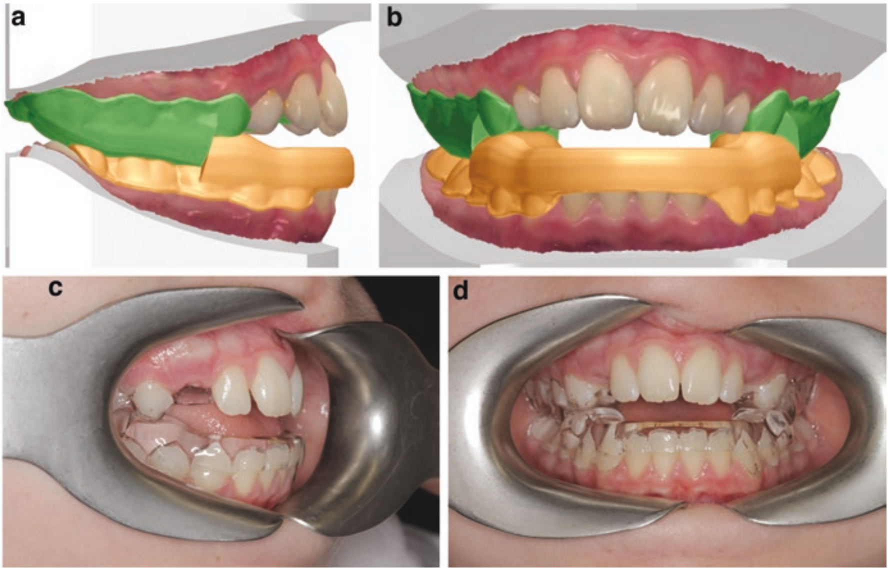
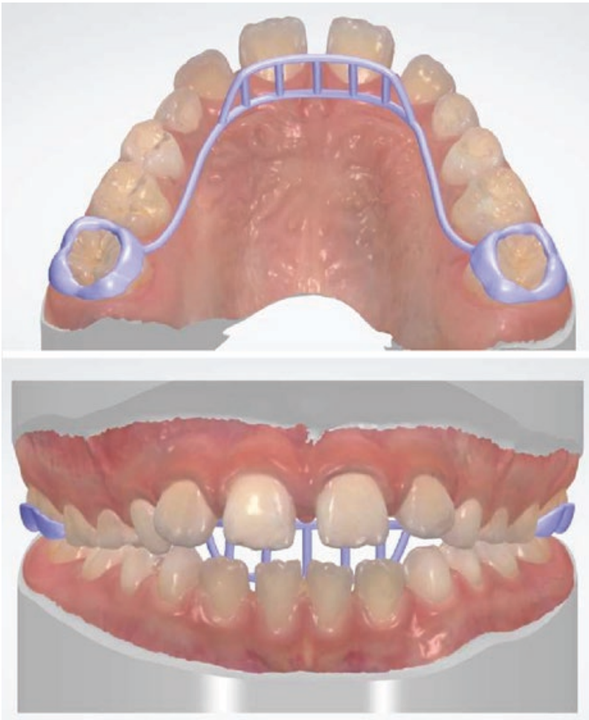


Fig. 7.27 (**a**) Side view appliance design. (**b**) Frontal view appliance design. (**c**) Side view 3D printed appliance. (**d**) Frontal view 3D printed appliance. Twin block style appliance designed using Appliance Designer (Reproduced with permission from JCO. Christensen LR. Digital workflows in orthodontics. J Clin Orthod. 2018;52(1):34–44) [31]

Fig. 7.28 Design of a banded tongue crib



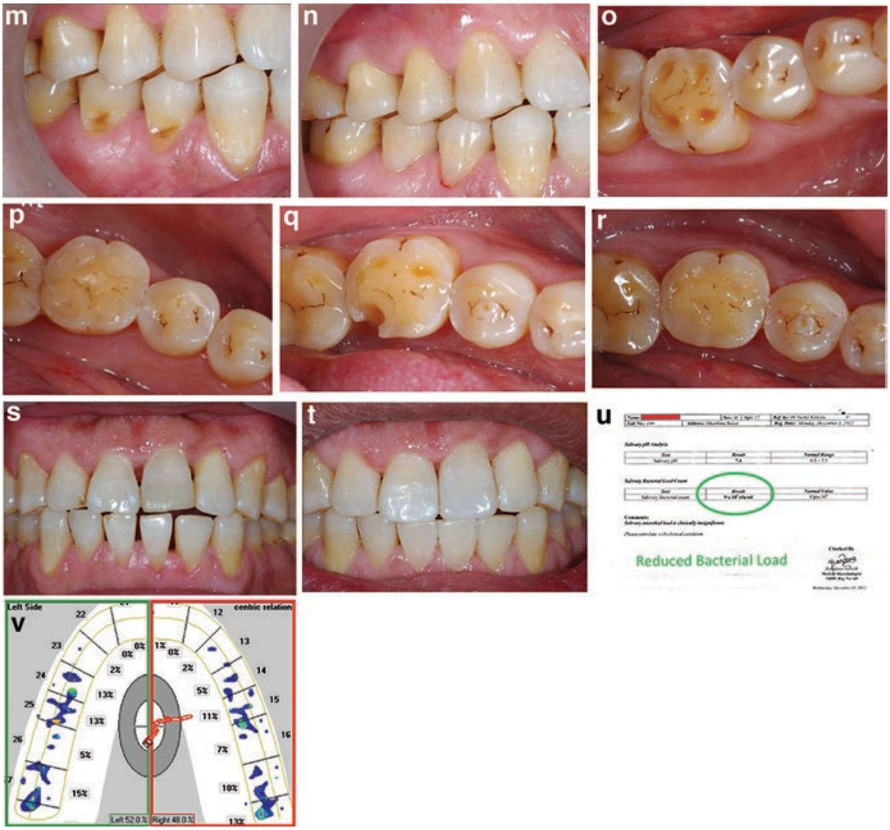


Fig. 8.11 (continued)

treatment performed was in accordance with the patient's desire using the simple approach of composite resin restorations and preventive force finishing protocol (occlusal force balance during the habitual bite of the patient), and night guard was given to protect night grinding and clenching habits of the patients.

Case 2 shows the *Oral Rehabilitation with Minimally Invasive Restorations and Preventive Force Finishing* (Fig. 8.12).

Case of a 62-years-old male with multiple signs and symptoms of Occlusal Force Disorders (OFD) (teeth erosion, abrasion, attrition, gingival recession, and notable occlusal forces disharmony). Digital occlusion analysis showed the overloading of occlusal force on tooth no 46, correlated with the thickening of PDL in radiology. Minimally invasive, quick and cost-effective treatment was performed. After routine oral hygiene prophylaxis and restorative treatment (restoration of abfraction, abrasion and erosion lesions using composite resin, and restoration of lost vertical

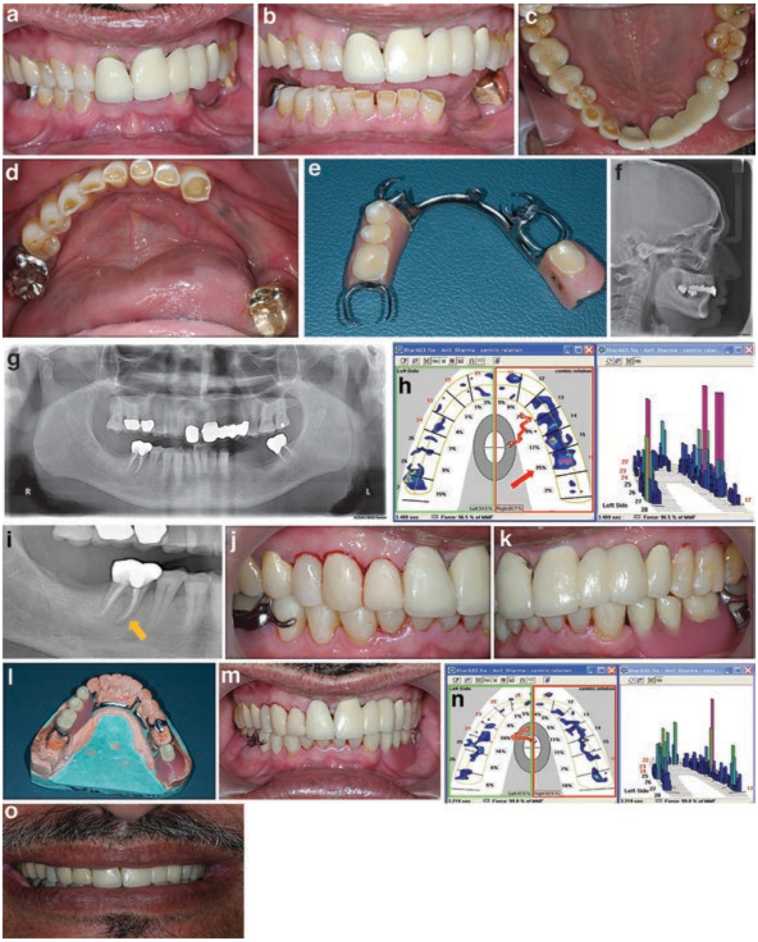


Fig. 8.12 (**a**) Intraoral view: collapsed bite with multiple missing posterior teeth. (**b**) Intraoral view: note multiple signs of Occlusal Force Disorders (attrition, erosion, abrasion, gingival recession). (**c**) Intraoral occlusal view: note enamel erosion on tooth no 12, 13, 14, and 26. (**d**) Intraoral occlusal view lower arch: note attrition of lower anterior due to reduced posterior support and bite imbalance. (**e**) A fully attrited cast partial denture that the patient was wearing. (**f**) CEPH X-ray collapsed bite. (**g**) OPG X-ray—note missing teeth, prominent mandibular angle, lost enamel in anterior region. (**h**) Occlusal Force Scan using T-Scan: Note the right side of the arch had 65.7% of occlusal load with high concentration of load (25%) on the tooth no 16 and occluding partner tooth no 46. The Center of Force icon was outside the inner circle showing occlusal force disharmony. (**i**) Digital occlusion analysis clearly showed the overloading of occlusal force (25%) on tooth no 46 which can be correlated with the thickening of PDL in radiology. (**j**–**l**) Restoration of abfraction, abrasion, and erosion lesions were completed using Beautifil II Composite resin from *Shofu, Inc, Kyoto Japan* . And restoration of lost vertical dimension of occlusion (VDO) was carried out by changing old metal crowns, restoring with composite overlay and fabrication of new lower cast partial denture as per new VDO. (**m**) After reconstruction of the compromised teeth and establishment of new VDO. (**n**) Occlusal force scan after Preventive Force Finishing. Note right and left side arch force balance, the high concentration of load on tooth no 16/46 was reduced. The Center of Force (COF) is now in the middle of the circle indicating proper force balance. (**o**) Smile after full mouth rehabilitation completed with minimally invasive approach

the creation of digital or physically printed 3D models that become working models for dental laboratories. The accuracy of scan bodies has meant that their use in cross arch situations is also possible. Indeed, scan bodies have also been employed in full arch situations for the development of milled multi-unit prosthesis in titanium, zirconia, and techno polymers. Some companies have also offered integration between scan bodies and custom abutment manufacturing (Figs. 12.6 and 12.7).

These custom abutments are often fabricated with a high degree of accuracy on either 5 axis lathes or computer numeric controlled lathes that are capable of

Fig. 12.6 Acuris conometric concept

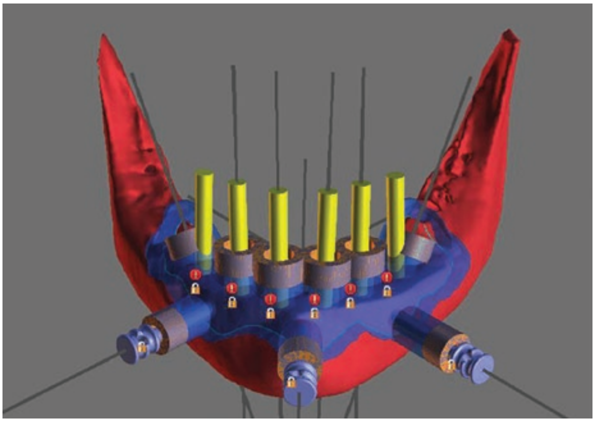


Fig. 12.15 Superimposable bone reduction and implant placement guides

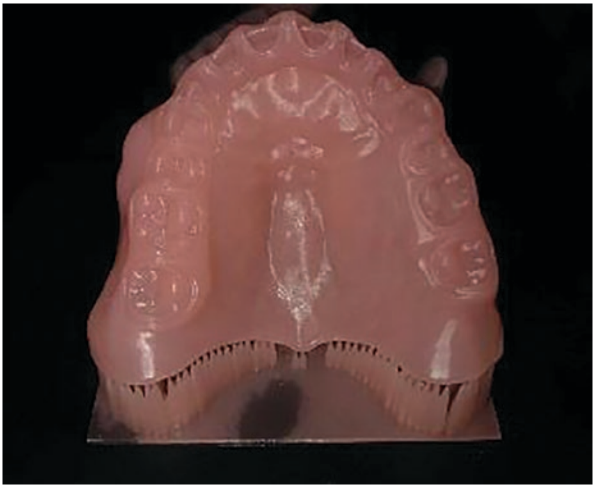


Fig. 12.16 3D Printed implant OVD base

accurate tooth, mucosa and bone supported surgical guides. 3D printing also allows for the fabrication of extremely accurate temporary implant prostheses that can be linked to a surgical guide (Fig. 12.16). New generation software also allows significant customization of these surgical guides, offering unlimited control over the dimensions of surgical componentry and offset distances. Surgical guides have therefore never been more customizable, and they continue to push the accuracy of surgical implantology to significantly higher levels.

12.7 Navigational Surgery

Another significant advance in guided surgery is navigational surgery. This technology does not even employ surgical guides as we know them but instead uses computed tomography in conjunction with a computer-guided navigation system

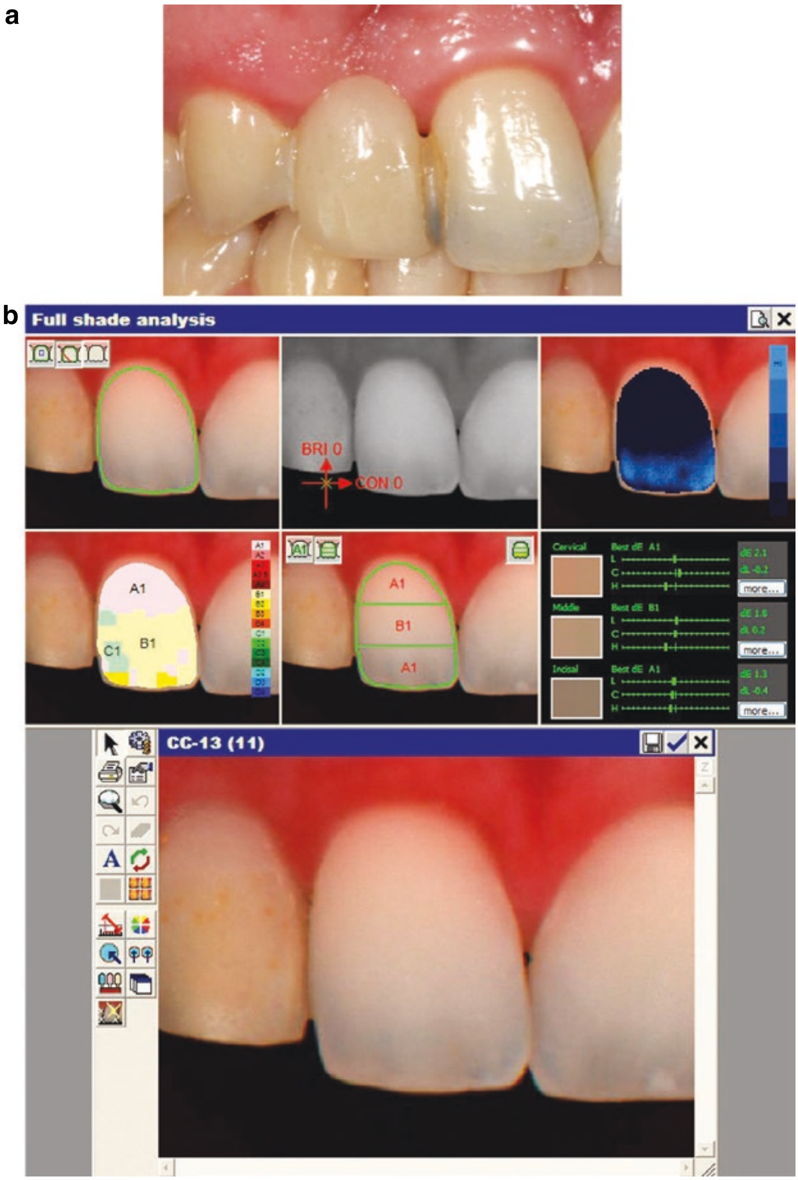
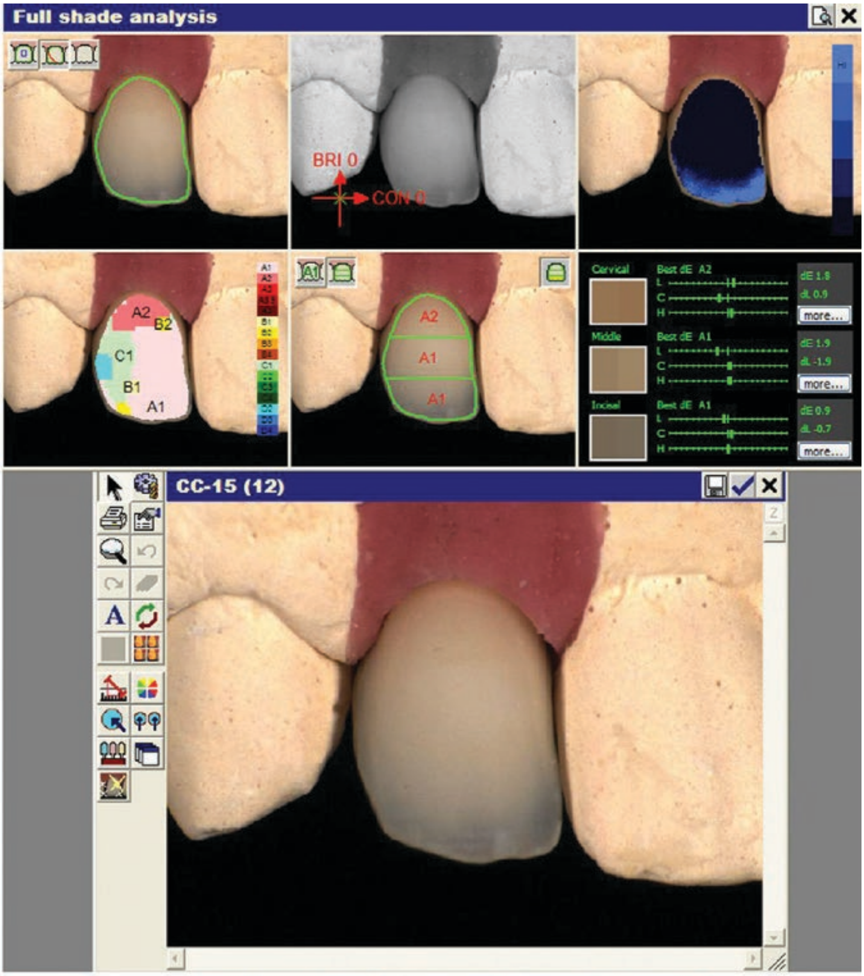


Fig. 13.13 Clinical application of SpectroShade Micro spectrophotometer. (**a**) Tooth #7 of a congenitally missing lateral incisor to be replaced with an implant [3i, Palm Beach, FL] and metal ceramic full-coverage restoration. (**b**) The SpectroShade Micro system creates a colour map which can be converted to several shade guide systems, this being the Classic Vita Shade Guide. It provides either an overall shade or the shade can be broken down into three distinct areas, cervical, middle and incisal, and provides detailed shade information in each of these areas and will provide a mathematical analysis resulting in a DE* value. (**c**) Virtual shade verification can be formed with this system so that shades can be assured prior to time-consuming patient visits. (**d**) Final restoration of tooth #7 with an implant and crown with an excellent aesthetic and functional outcome (*Reproduced with permission from Elsevier Publishing)*

c



d

Fig. 13.13 (continued)

glabella, nose, and chin. The horizontal and vertical lines are crossed against each other to measure symmetry and cant of the face [38].

Grouping of the lines and the facial photographs is done for better analysis of smile. Midline discrepancy, occlusal plane shifting and canting can be easily detected. Dento gingival analysis is done next to establish the smile curve.

Three transferring lines are drawn over the retracted smile view as:

(a) *Line 1:* From the tip of one canine to the tip of the contralateral canine.
(b) *Line 2:* From the middle of the incisal edge of one central incisor to the middle of the incisal edge of the contralateral central incisor.
(c) *Line 3:* Over the dental midline, from the tip of the midline interdental papillae to the incisal embrasure.

These lines help in calibrating four features on the photograph: size, canting, incisal edge position, and midline position. Line 1 will guide the two first aspects (size and canting), line 2 will guide the incisal edge position, and line 3 will guide the midline position. The width/ length proportion of the central incisors is measured, and a rectangle is then placed over the edges of both central incisors on a digital image. The proportions of the patient's central incisors can be compared to the ideal proportions described in the literature.

As required, more lines may be drawn to evaluate both teeth and gingiva of the patient's maxillary arch, including tooth proportions, interdental relationship, relationship between the teeth and smile line, discrepancy between facial and dental midlines, midline and occlusal plane canting, soft tissue disharmony, relationship between the soft tissues and teeth, papillae heights, gingival margin levels, incisal edge design, and tooth axis. These lines may either be drawn over the photograph or copied and pasted from the software.

Required changes can be accomplished with the help of a digital ruler (Fig. 13.19) which is calibrated against the photograph by measuring the width of the central incisors in the study model. Figure 13.20 shows the procedure of digital smile designing on a DSD 3D software [39].

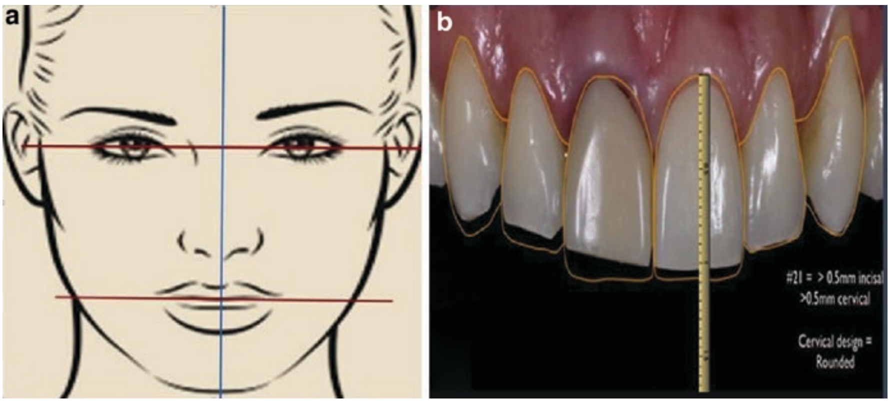


Fig. 13.19 (**a**) Facial view with horizontal and vertical reference lines, (**b**) Digital ruler *(Reproduced with permission from Elsevier Publishing)*

This digitally approved smile design at this stage can be used to create physical mock-up which can be tested aesthetically in the patient's mouth. After drawing the lines and markings on the cast, it is possible to transfer any necessary information, such as gingival margins, root coverage, crown lengthening, incisal edge reduction, and tooth width. At this stage, information that includes all the measurements and markings are hand over to the technician, which will be required to develop a precise wax-up on both the slides and cast.

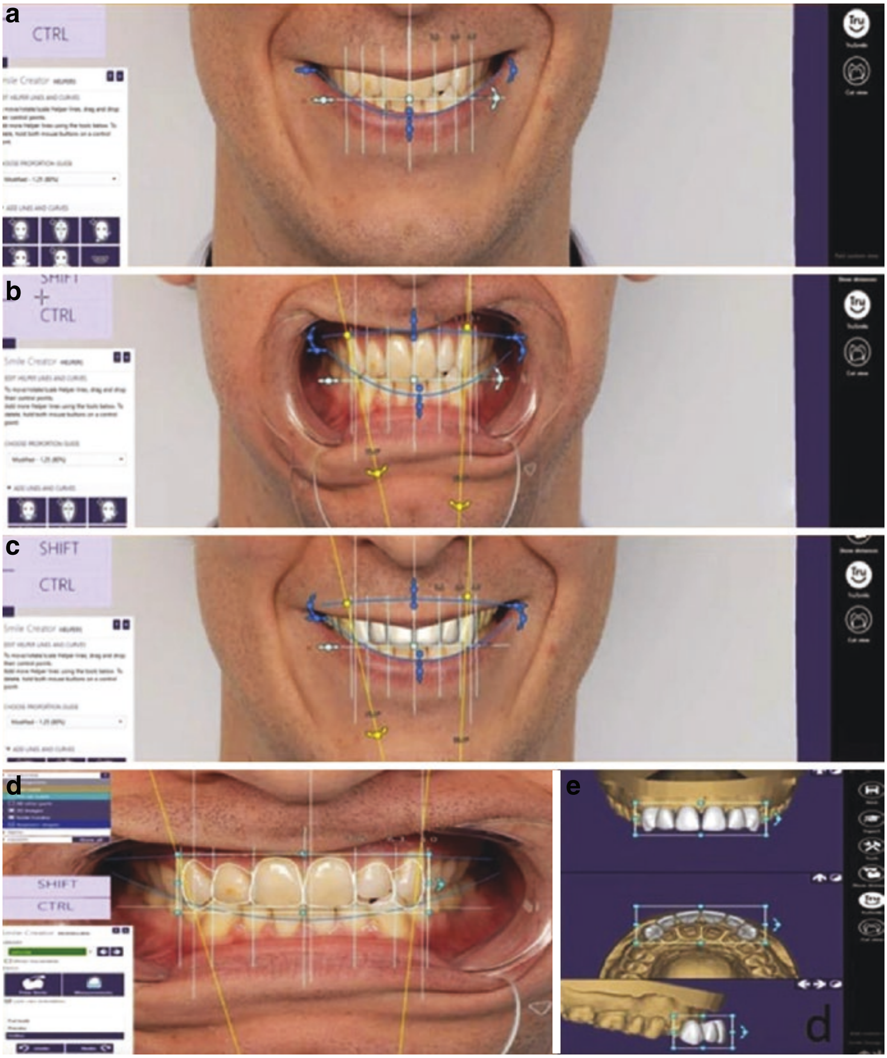


Fig. 13.20 Digital smile designing process. (**a**, **b**) shows drawing of facial and intraoral reference lines. (**c**) shows integration of facial with dental analysis. (**d**) represents incorporation of ideal dental contours in 3D. (**e**) shows digital designed smile compared with original smile *(Reproduced with permission from Elsevier Publishing)*

The guided diagnostic wax-up will be an important reference for any surgical, orthodontic, and restorative procedures. Several guides can be produced over this wax-up to control the procedures, such as surgical stents, orthodontic guides, implant guides, crown lengthening guides, and tooth preparation guides. The next important step is to evaluate the precision of the DSD protocol and the wax-up which is to be used for clinical try-in.

While DSD presents many advantages over more traditional treatment planning methods, the mock-up technique is still regarded as an objective and efficient tool in treatment planning, communication and used to confirm the treatment plan before the final preparations and evaluate final restorations within the limitations of biological and functional considerations. The mock-up can be a clinical confirmation of the digital tool and any occlusion discrepancies can be corrected at this stage (Figs. 13.21 and 13.22).

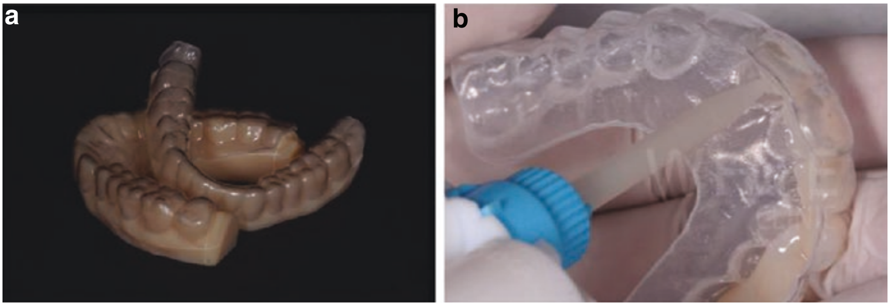


Fig. 13.21 (**a**) Matrix for the motivational mock-up and digital models. (**b**) Motivational mock-up made with bisacryl

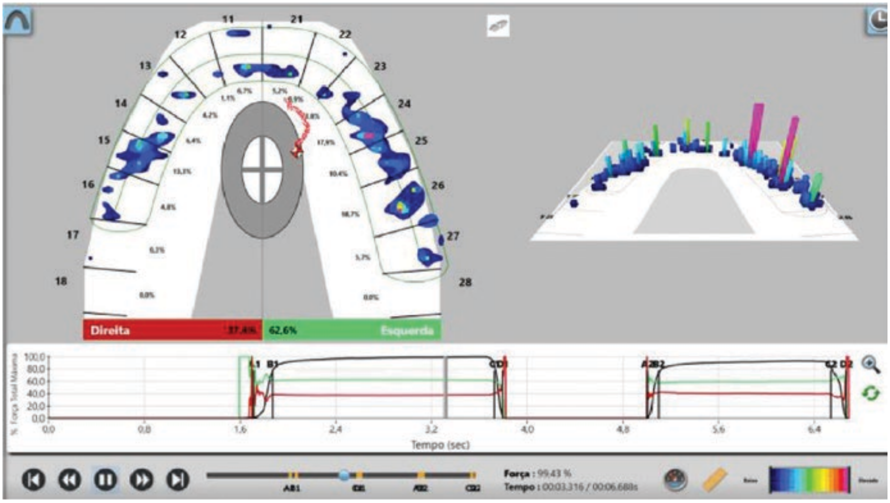


Fig. 13.22 Occlusion confirmed using T-scan technology