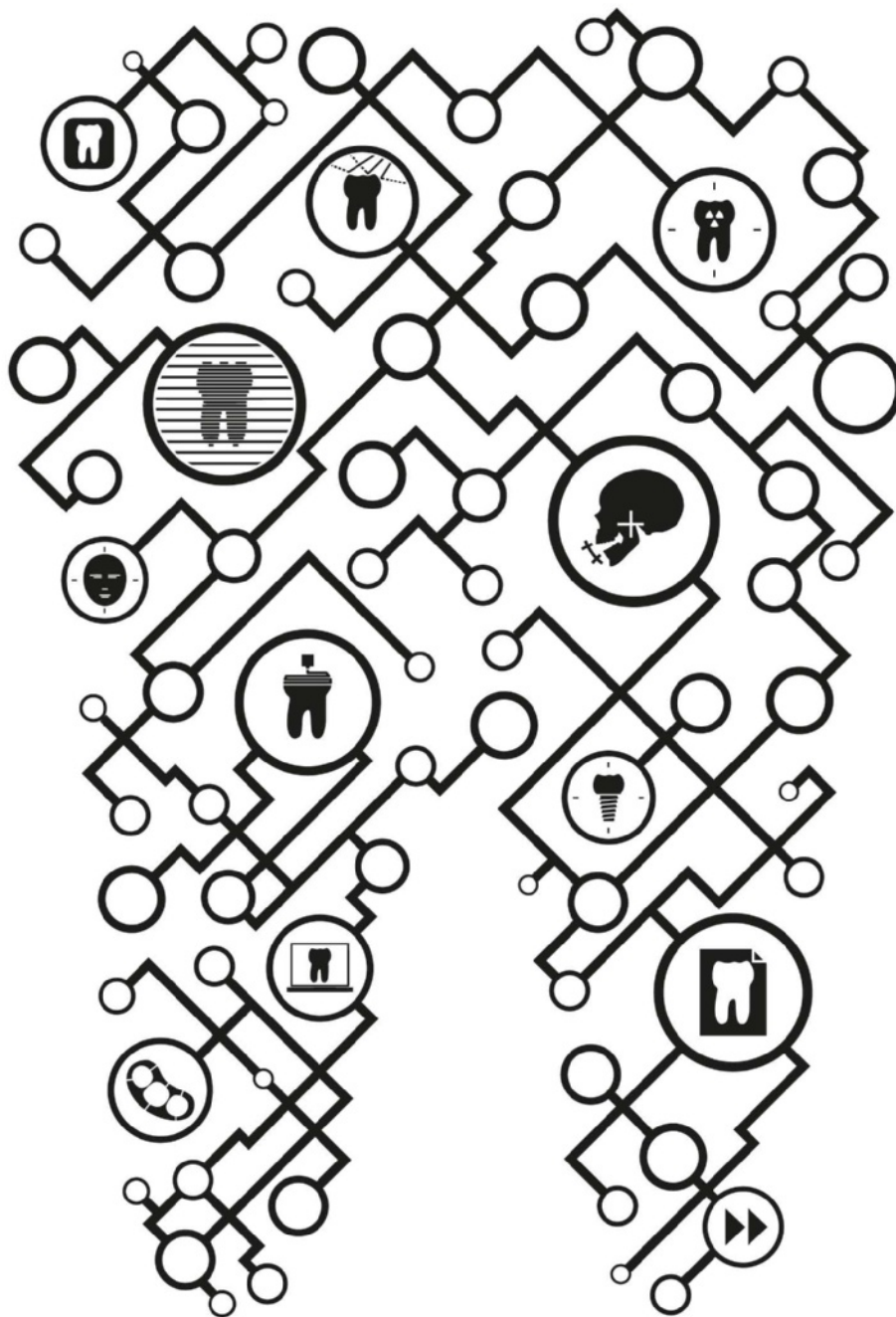


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Digital Workflow in Reconstructive Dentistry



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List of Abbreviations

AI	artificial intelligence
ALARA	as low as reasonably achievable
AWS	active wavefront sampling
BFT	bite fusion technique
CAD	computer-aided design
CAI	computer-aided impressioning
CAM	computer-aided manufacturing
CBCT	cone-beam computed tomography
CCD	charge-coupled device
CEJ	cementoenamel junction
CLIP	continuous liquid interface production
CMOS	complementary metal oxide semiconductor
CNC	computer numerical control
COS	chairside oral scanner
CT	computed tomography
CTE	coefficient of thermal expansion
DICOM	Digital Imaging and Communications in Medicine
DLP	digital light processing
DPI	dots per inch
DQE	detector quantum efficiency
DVT	digital volume tomography
EPR	electronic patient records
FDP	fixed dental prostheses
FGP	functional generated pathway
FOV	field of view
FPD	flat panel detector (can also mean fixed partial denture)
GDPR	General Data Protection Regulation
IGS	image-guided surgery
IOS	intraoral scanner
LED	light emitting diode
LTD	low temperature degradation
MgPSZ	magnesium-doped partially stabilized zirconia
MRI	magnetic resonance imaging
OCT	optical coherence tomography
PACS	picture archiving and communication system
PEEK	polyether ether ketone
PFM	porcelain-fused-to-metal
PMT	photomultiplier tube
PSP	photo-stimulated phosphor plate
RDP	removable dental prosthesis
RNC	resin nano ceramic

ROI	region of interest
SL	stereolithography
SLM	selective laser melting
SLS	selective laser sintering
STL	Standard Tessellation Language
TFT	thin film transistor
TIFF	Tagged Image File Format
TMJ	temporomandibular joint
UV	ultraviolet
VDO	vertical dimension of occlusion



Preface

Innovations and their introduction as products for users seem to be the steering wheel of contemporary industry. The domination of technology and tech-driven companies is not surprising. Apple, Google, and Microsoft have been progressively expanding their development and production capabilities to cover areas not primarily related to their main revenue streams. A good example is the burgeoning smartphone industry. Obviously, all major IT companies are now involved in this business. It is needless to mention that this industry has not only opened the way for a great number of hardware development companies, but has also enabled millions of small start-up software and application development companies and individuals to pair their innovations with the major players. It is clear today that it is all about innovation and small, yet unique cutting-edge ideas and their implementation in the proper environment (team, funding, and support). A small search online reveals countless start-ups with very promising innovations.

The picture is quite similar in health sciences. Innovations are being continuously introduced with the ultimate goal of achieving better and faster patient care. In dentistry, the digital revolution has already arrived. Words like scanning, machining, milling, printing, CAD, and CAM are being used on a daily basis. As the avenue of innovations is endless, the current technologies available are all considered blueprints for future developments. Although research and development are ongoing in the field of digital dental medicine, the activities seem to be mainly based on existing dentistry-derived technologies and led by the idea that “we need to do it as well.” A good example is intraoral scanners. Though not new, intraoral scanners are being introduced continuously by nearly every dental company. A critical comparison between the available scanners clearly shows that the implemented technologies in all current scanners are, to a large extent, very similar. Despite continuous introduction of new versions of intraoral scanners, it is amazing that the application spectrum has not been expanded to cover the important indication of full-arch scans, and the complete digital workflow is still lacking. Clearly, “out of the box thinking” is needed in dentistry.

Digital Workflow in Reconstructive Dentistry is the result of efforts made by the academic team at the Department of Prosthodontics, University Hospital of Freiburg. It aims to build a fundamental understanding of the general principles, science, and clinics of digital dental medicine. The information provided within these pages summarizes the various components of the digital workflow in reconstructive dentistry and discusses their advantages and disadvantages. Moreover, insights are provided about upcoming, game-changing technologies. By reading this book, students, clinicians, and researchers will gain and enhance their knowledge about digital dental medicine and identify the areas they need to focus on next in order to integrate the available technologies in their daily work. Clearly, the path of digital dental medicine will not stop here.



We would like to thank all contributors for their dedication to make this book a reality. Much appreciated is the work of the outstanding lab technicians, namely Udo Plaster, Manfred Pörnbacher, Ulrich Lamott, and Wolf Wörner. Likewise, the support and exchange of information with companies, manufacturers, and developers helped tremendously to refine the information provided by this book.

Wael Att
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Jörg R. Strub

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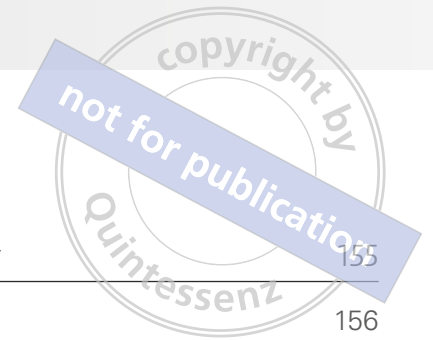


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A large, light gray stylized graphic of a tooth is positioned on the left side of the cover. The tooth is set within a rounded square frame, which is itself enclosed by a larger, thin gray arc that curves around the top and right sides of the tooth.

DIGITAL WORKFLOW IN RECONSTRUCTIVE DENTISTRY: AN INTRODUCTION

Wael Att



Introduction

The digital revolution is impacting nearly every aspect of our daily life. Today, it is nearly impossible to find a person that is not connected to the internet and performing regular tasks using a mobile device. While many advantages exist with this connectivity, there are disadvantages as well. The abbreviation “FOMO,” which stands for “Fear of Missing Out,” was introduced to the *Oxford English Dictionary* in 2013. Whether it is a problem or not, nonscientific observations report that more than 70% of people are addicted to social media. In fact, every bedroom has today a “connected” mobile phone beside the bed. True also is that for many of us the mobile phone is the first and last thing we see every day. While this practice is not new, however, it did not exist 10 years ago. Further examples about the necessity of the use of smart phones include, but are not limited to, access to information via search engines, mobile banking, home and office control, access to database reservation systems, entertainment, and so on. Such examples clearly show how digital revolution has been aggressively emerging and impacting every aspect of our daily life.

Similar to these aspects I have just mentioned, the medical field is also being impacted by digital technology. While diagnostic means and treatment concepts are being continuously refined, the emergence of new technologies is driving the implementation of new concepts with the goal of improving patient care and offers the new generation of physicians and scientists better learning and development opportunities. A good example is the use of artificial intelligence (AI) in medicine. This has been pushed after realizing the significance of analyzing extremely large databases, termed “Big Data,” computationally to reveal patterns, trends, and associations, especially relating to human behavior, interaction, and disease progression. While many companies and start-ups are focusing on developing products and software that utilize AI in medicine, Watson Health (Microsoft, Redmond, WA, USA) is considered the first and most advanced AI-based system used for helping healthcare. It enables professionals to share health data and deliver insight to further care through hospitals, providers, insurers, researchers, and patients. The developer states that it is humanly impossible today to keep up with the daily proliferation of healthcare data. As an example, healthcare data is projected to be greater than 2,310 exabytes by 2020. A one-week stay in a hospital can equal hundreds of pages in electronic health records. The global economic impact of chronic disease by 2030 is estimated to be 47 trillion USD. Comparatively, only 10% of the drugs currently in development make it to the market (source: IBM Watson Health). All of these facts have driven the need to create a connected ecosystem across the healthcare industry to harness expertise from this information and determine shared value with the goal to advance health and human services. Of course, IBM Watson is not alone – there are currently thousands of companies and start-ups focusing on AI in healthcare.

According to the *Merriam-Webster* dictionary, seven definitions of the word digital are listed. The first is “of or relating to the fingers or toes,” while the second





is “done with a finger,” both of which apply to dentistry at large. Another definition is “composed of data in the form of especially binary digits/digital images/photos/a digital readout/a digital broadcast.” Wikipedia, the free encyclopedia, refers to digital dentistry as “the use of dental technologies or devices to carry out dental procedures rather than using mechanical or electrical tools.”

Clearly, the dominance of computer-aided design/computer-aided manufacturing (CAD/CAM) and its applications is rather evident in the field of digital dental medicine. This may be attributed to the large contribution of the industry in research and development (R&D) over the past half century and its commercial ramifications. Having said that, the digital dental world is not and should not be considered solely for its restorative dental applications. To start at the very beginning: dental education departments in many academic institutions the world over are implementing digital aspects in their curricula while training young dentists.

This includes the application of digital in basic sciences (e.g., simulations in anatomy, physiology, and pathology) or clinical sciences (e.g., virtual and haptic training of tooth preparation or dental shade matching). Also, most diagnostic sciences in dentistry such as radiology rely almost exclusively nowadays on digital media. The days of chemical processing of X-ray films and the lack of consistency of the development of such images are gone. Along with the introduction of digital technologies (e.g., computers, laptops, tablets, scanners, and a wide spectrum of software applications) this has dramatically changed the practice of dentistry. Today, a vast array of digital technologies is already being used in daily practice. Such tools range from patient data management and organization software for patient data acquisition (medical and dental history, extraoral findings, intraoral and dental findings, periodontal findings, functional findings, and/or radiographic findings) to diagnosis, treatment planning, and treatment execution. Consequently, it is rather evident that digital and dentistry have virtually become synonyms and are inseparable.

This chapter will serve as a brief introduction to the components of digital dentistry and areas of implementation.

What is the Digital Workflow?

The digital workflow in reconstructive dentistry has been described by Att and Gerard (2014)¹ as comprised of three main components; starting with data acquisition, followed by data processing and planning, and finally with the execution of treatment or fabrication (Fig 1.1).

For the first component “data acquisition,” there are many technologies available. The goal is to transform the patient’s information into digital data that can be used for further steps, such as analysis, treatment planning, and processing/planning. Some of the acquisition techniques available encompass digital charting, intraoral or desktop scanners, digital radiography, digital photography, video recordings, and so on. As an example, digital photography is considered an important acquisition tool. It is widely used today for documentation and communication pur-

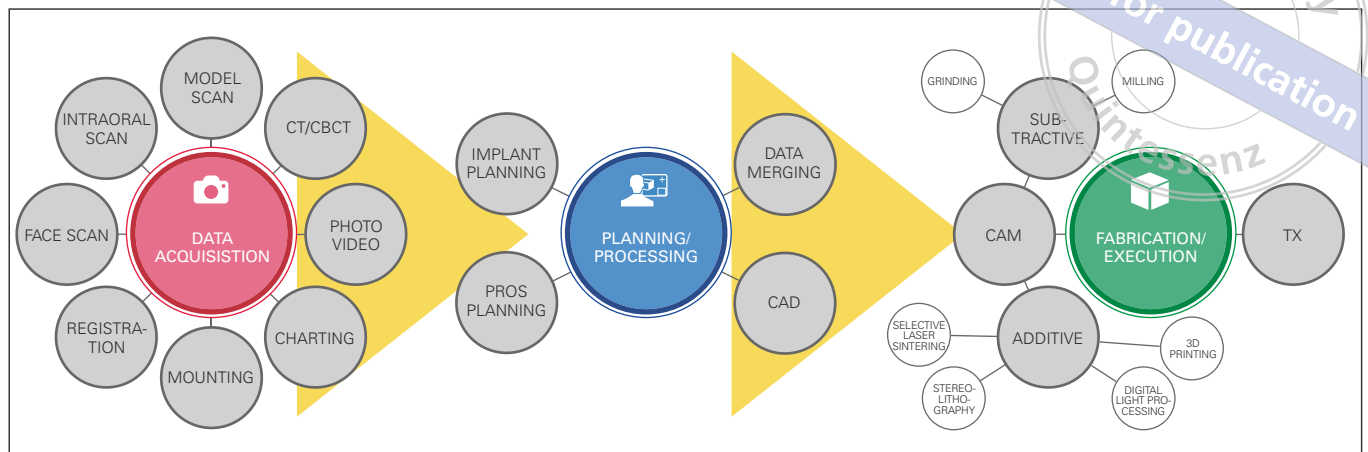


Fig 1.1 Overview of the digital workflow in reconstructive dentistry.¹

poses. Together with the appropriate software and online or cloud-based communication platforms, the photos can be used as a part of comprehensive treatment and esthetic analysis and, at the same time, as an important communication tool among the dentist, the dental lab, and the patient.

In cases of smile enhancement, for example, providing photos and videos of different stages of the rehabilitation (try-ins, mock-ups, and so on) helps the dental laboratory technician to optimize the esthetic reconstruction, thus reducing the in-office patient treatment time during try-in. On the other hand, the use of intraoral scanners to perform computer-assisted impressions is considered today as a predictable and a fast tool for the purpose of digitizing and manufacturing small-unit reconstructions.

The next step of the workflow encompasses “processing/planning” of the data acquired in order to set a treatment plan or design a restoration. One of the important aspects here is so-called data matching, where data sets obtained from different acquisition tools (e.g., intraoral scan and cone-beam computed tomography (CBCT) or patient photos superimposed onto model scans) can be merged/superimposed together using specific planning software in order to enhance the information for the dentist or lab technician on the computer screen. Most software companies are intensively working on introducing software that can combine more than two different data sets (e.g., surface scans of the intraoral situation, CBCT, face scan, jaw movement data, and so on). The ultimate goal is to create the completely virtual patient. Such a development would push the digital workflow at an even speedier pace and allow for faster adaptation by practitioners, technicians, and teachers. This topic is described elsewhere in this book.

For clarity in “treatment and fabrication,” it is important to mention that CAD/CAM is considered as a component of the digital workflow. Per definition, CAD is the use of a computer to assist in the creation, modification, analysis, or optimiza-



tion of a design. CAD software is used to improve the productivity of the designer, the quality of the designs, and the communication through documentation as well as to create a database and a three-dimensional file for manufacturing. Once the CAD process is complete, the generated files are transferred to a local or a remote CAM solution. Here, a software and process are required to enable fully automated manufacturing of dental restorations by preparation of the generated CAD files for subtractive or additive manufacturing machines. While CAM has been successfully performed via subtractive techniques, the increased use of additive manufacturing technologies, such as 3D printing, stereolithography, selective laser sintering, and other methods is remarkable. Concepts related to the different components of the digital workflow that are being used on contemporary dental offices are briefly discussed in this chapter. The next chapters of this book provide an in-depth focus onto the different components of the digital workflow.

Data Acquisition

As already described, data acquisition is the first step of the digital workflow.

While many acquisition technologies exist, the most-used components are patient management systems, including dental charting software and radiography. While dental offices performing patient registration and “conventional” charting by means of paper form are becoming history, many dental offices and dental schools are using the digital approach using different commercially available software for Electronic Protected Health Information (ePHI). With such software, different patient data and information can be obtained and stored for later use.

Typically, medical and dental history as well as comprehensive charting, including radiographic analysis, can be stored. Large-scale clinics and institutions use network-based software that facilitates access of patient data from different working stations. However, concerns remain about patient privacy and data access. For these it is highly recommended to use software that guarantee patient information (i.e., which implement the ePHI). To facilitate this, the software are required to be compliant with the Health Insurance Portability and Accountability Act (HIPPA) in the United States or with the General Data Protection Regulation (GDPR) across the European union.

The goal is to protect all “individually identifiable health information” held or transmitted by a covered entity or its business associates, in any form or media, whether electronic, paper, or oral. “Individually identifiable health information” is information, including demographic data, that relates to (a) the individual’s past, present, or future physical or mental health or condition; (b) the provision of healthcare to the individual; or (c) the past, present, or future payment for the provision of healthcare to the individual; and that identifies the individual or for which there is a reasonable basis to believe it can be used to identify the individual. Individually identifiable health information includes many common identifiers (e.g., name, address, birth date, ID number, social security number, and so on). Further iden-

tifiers include, but are not limited to patient facial photographs, annotated/named radiographs, models, intraoral scan data, face scan data, or any other identifiable data. Therefore, it is important for all staff members of any clinic or institution to understand and implement patient privacy standards and guidelines.

Data Processing / Planning and Treatment Planning

While some software incorporate both acquisition and processing/planning capabilities, the majority of developers currently separate them in different software to avoid complexity and introduce clarity into the workflow. Data processing/planning software can be introduced by the same manufacturer of the acquisition device/tool or by another. A good example is the use of acquisition software for an intraoral scanner and CAD from the same device manufacturer (e.g., Sirona or 3Shape). Another possibility is to use processing/planning software that is developed by a different manufacturer than the acquisition software. An example here is the use of CBCT data obtained from a specific manufacturer and imported into implant planning software from a different developer. While this procedure is common, it is important to have the files/data prepared in universal way that the majority of the software can read. Here, the most commonly used universal file formats, among others, are Joint Photographic Experts Group (JPEG), Digital Imaging and Communications In Medicine (DICOM), Standard Tessellation Language (STL), Geometry Definition File Format (OBJ), Tagged Image File Format (TIFF), and Moving Picture Experts Group 4 (MP4). Whenever these files are the output by an acquisition software and can be easily imported and read by the processing/planning software, the workflow is considered as an open system. In the case where the output file is not universal, it must be read by a specific processing/planning software that is typically from the same acquisition device/software developer, so the system is considered to be closed. With some closed systems it is still possible to export the data in a universal format or, in other words, to convert from a closed to an open system. Here, the software developer typically charges fees for this conversion, termed as a *click fee*.

Typically, the processing/planning software can be used for analysis and diagnostics (e.g., caries and lesion detection), treatment planning (virtual mock-up, virtual implant treatment planning, virtual orthodontics treatment planning, and so on), or CAD. In terms of caries and lesion detection, several companies are working now on introducing AI for automatic detection of caries as well as further pathological lesions from radiographs, namely periapical radiographs, panoramic radiographs, or CBCT. Also, AI is being implemented for automatic annotation of different anatomical structures, such as mandibular nerve, impacted teeth, maxillary sinus, floor of the nose, and others. Likewise, there are undergoing develop-



ments to enable automatic detection and segmentation of the teeth from CBCT and creation of separate files (STLs) of the teeth, as well as the bony structures. The implementation of such technologies in the near future will accelerate the workflow and enhance the diagnostic experience for the clinician, thus providing a better healthcare service for the patient.

Data processing/planning software for treatment planning is one of the most important components of the digital workflow. It is not only intended for communication between the patient and the treatment team, but also an important tool for treatment planning and expectations. A good example is implant planning software, where CBCT data (typically DICOM files) is imported into the software and used to plan the implant position virtually with consideration of the anatomical structures as well as the restorative needs. Another application is the use of patient facial photographs in combination with calibrated intraoral scan or model scan data to analyze and plan the future esthetic rehabilitation (e.g., smile design software) in terms of tooth length, width, and proportions, as well as shade, and share the information with the patient as well as the treatment team. While such features facilitate design capabilities, CAD is considered the last component of data processing/planning. Here, the software is used to design the form of the intended object (e.g., crown, prosthesis, surgical guide, night guard, virtual wax-up, and so on) before moving to the last component of the digital workflow.

Execution of Treatment or Fabrication

The last component of the digital workflow is to perform the planned treatment or production of the intended object by means of computer-aided manufacturing (CAM). CAD data is imported into CAM software, where details of the production process can be simulated and executed (e.g., placement of supportive structures or simulation of the milling/grinding process). Both the subtractive and the additive manufacturing technologies are available for CAM.

The subtractive technologies can be subcategorized into milling and grinding. It is considered as the most widely spread manufacturing technology. The manufacturing machines can be divided into chairside or lab units. In the former option, the unit is typically intended for the manufacture of single-unit restorations during the same office visit. For a larger-scale production and more demanding units/restorations, the latter option is selected. The milling machine can be either in an office, a laboratory, or a central manufacturing facility. On the other hand, additive manufacturing is becoming increasingly popular. Here, several methods are available for manufacturing of an object, including but not limited to selective laser sintering (SLS), digital light processing (DLP), stereolithography (SL), and three-dimensional printing (3D printing). The latter technology is considered to be the most up to date and improving day by day. However, the scientific evidence about its accuracy and efficiency is still limited. Comparatively, the other additive manufac-

turing technologies are well established. For example, SL is considered for a long time as the method of choice for central manufacture of surgical guides or models with a predictable accuracy. Also, SLS is being used to produce nonprecious alloy frameworks of crowns and fixed partial dentures with a predictable accuracy. While many techniques already exist, significantly further technologies and materials for additive manufacturing are expected to be introduced within the next few years. Further details about the different CAM technologies are provided in Chapter 10.

References

1. Att W, Gerad M. Digital workflow in reconstructive dentistry: new technologies for high-strength ceramics. In: Ferez J, Navarro J, Silva N (eds). High-Strength Ceramics. Chicago, IL: Quintessence Publishing, 2014.



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CASES



CASE 3: DIGITAL WORKFLOW FOR THE REMOVABLE IMPLANT-SUPPORTED REHABILITATION OF AN EDENTULOUS JAW

Wael Att, Aiste Gintaute, Michele Frapporti, and Udo Plaster

Introduction

In the edentulous jaw, the decision between an implant-supported fixed or removable dental prosthesis depends mainly on the patient's general health and wish, financial capability, interjaw relationship, bone quantity to facilitate placement of a sufficient number of implants, and the need for soft tissue support.¹⁻⁴ In many cases, the need for significant soft tissue support (i.e., lip support), dictates the delivery of a removable implant-supported rehabilitation. Specifically, in cases of resorbed maxilla, the white and pink portions can easily be labially positioned to provide proper lip support, thus compensating for the lack of tissue support and simultaneously facilitating proper hygiene. The following case provides a step-by-step description of the treatment for an edentulous maxilla with an implant-supported removable rehabilitation using a digital approach.

Case Description

A 57-year-old female patient presented at the Department of Prosthodontics, School of Dentistry, University Hospital of Freiburg, for consultation and treatment. Her chief complaints included excessive mobility and unpleasant appearance of the teeth. The patient's medical history showed a good general condition, with no current therapy or medication.

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Go online to see a video showing the fusion of different data sets.

15



Go online to see a video of implant placement in the maxilla.

Fig 11.3-1 Enface photos at the first visit appointment. The face displays normal proportions (left). A forced smile reveals asymmetric central incisors with crowding, giving the smile an unesthetic appearance (right).



Fig 11.3-2 The maxillary teeth appeared disharmonious and associated with black triangles. The smile was rated as displeasing.



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Fig 11.3-3 A comprehensive clinical examination and analysis revealed multiple missing teeth and insufficient restorations in both jaws. A generalized advanced chronic periodontitis was diagnosed. Due to attachment loss and elongation (migration) of the teeth, the general esthetic appearance of the teeth in both jaws was deemed as compromised. In addition, the mobility ranged between grades I and III. Functional examination with the existing interim prosthesis revealed multiple contacts in maximal intercuspitation with group guidance during lateral and protrusive movements.

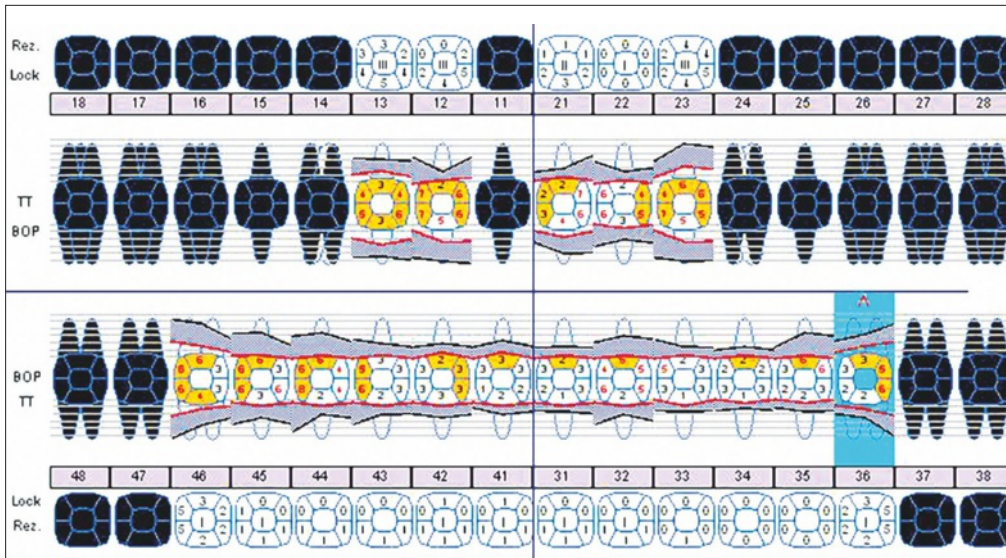
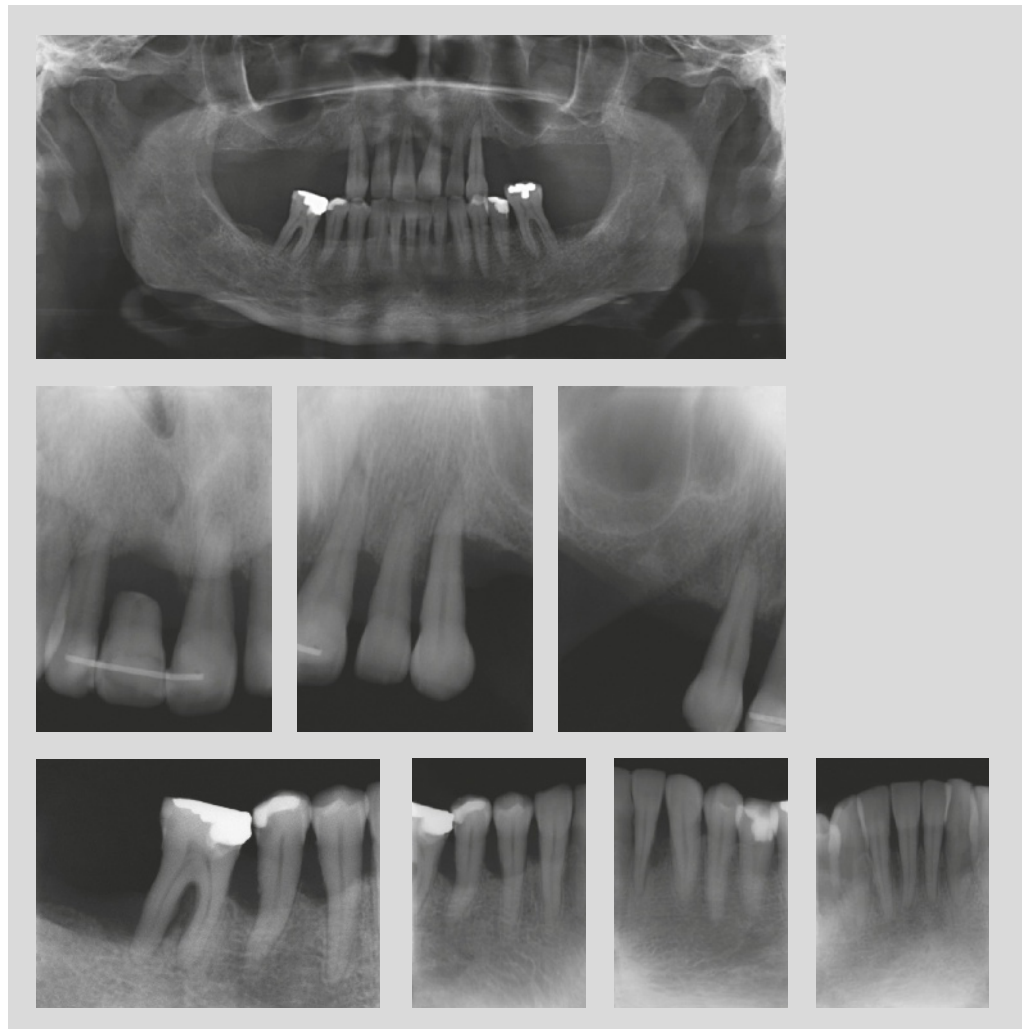


Fig 11.3-4 Occlusal view showing the situation at the first visit (top right and left). Due to instability and poor fit, the maxillary provisional prosthesis was rated as insufficient (bottom).



Fig 11.3-5 The panoramic radiograph and a full-mouth survey depicted advanced generalized bone loss as well as pneumatization of the maxillary sinuses (top). Based on the clinical and radiographic findings, the remaining maxillary teeth were given a poor prognosis. With the exception of tooth 46, all mandibular teeth were given a questionable prognosis (bottom). The final treatment plan included the delivery of an implant-supported removable dental prosthesis in the maxilla and tooth and implant-supported single crowns in the mandible.⁵⁻¹⁸ A bilateral sinus elevation procedure was planned in order to enhance bone volume in the maxilla.¹⁹⁻²³ Six implants to support a bar-type removable dental prosthesis in the maxilla were planned.^{6,7,9-11,13,14,18,24}



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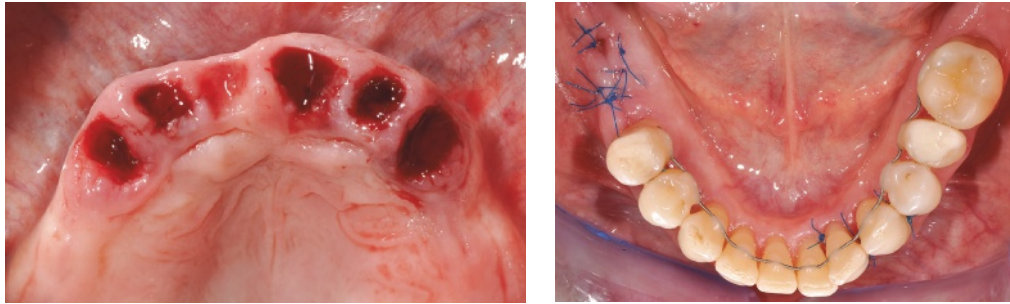


Fig 11.3-6 After initial debridement, the remaining maxillary teeth as well as tooth 46 were extracted. In addition, the mandibular teeth were splinted with a wire to reduce mobility and facilitate a proper environment for periodontal tissue healing (top left and right).²⁵⁻³⁰ The patient received an immediate denture at the time of tooth extraction (bottom left and right). A re-evaluation of the periodontal status 8 weeks after initial treatment revealed a significant reduction in pocket depth and bleeding upon probing.

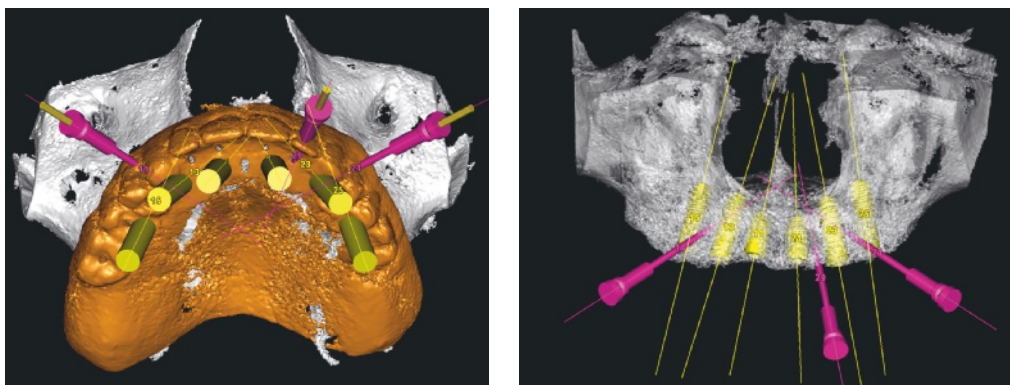
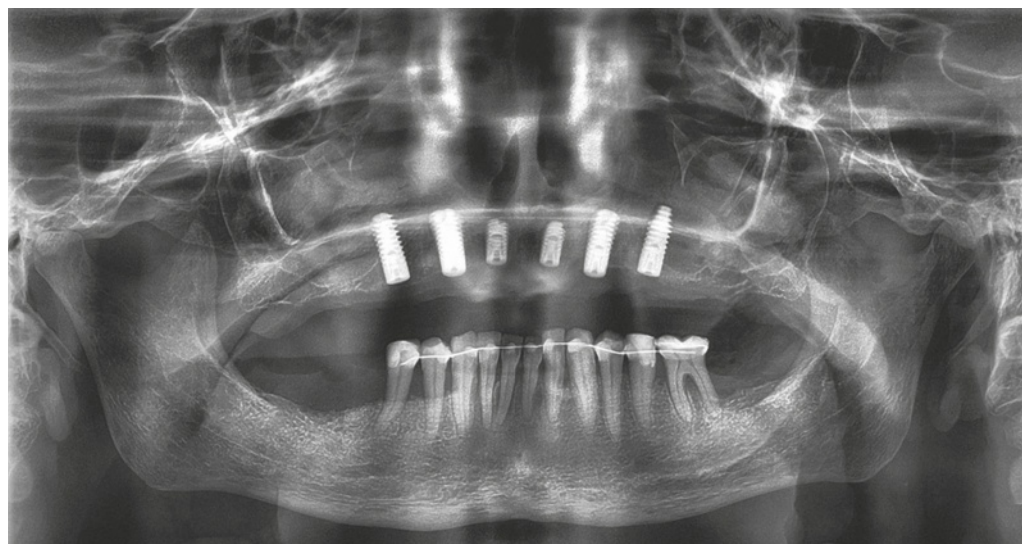


Fig 11.3-7 After proper healing of the extraction sites and elimination of the inflammation, preimplant diagnostics were performed (top left). The interim prosthesis was replicated using a 20% barium sulfate-containing polymethyl methacrylate (PMMA) resin material to fabricate an imaging appliance (top right). Here, it is highly recommended to include (drill) a hole in every tooth in the imaging appliance in order to guide the central tooth axis. As mentioned earlier, this procedure eases identification of the central tooth axis on the computer screen. Then, cone-beam computed tomography (CBCT) imaging was carried out with the imaging appliance placed. Digital imaging and communications in medicine (DICOM) data were imported into the planning software (Simplant Pro 17, Dentsply Sirona, Mannheim, Germany), where prosthetically oriented implants as well as fixation screws for the surgical guide were virtually planned (bottom left and right).

Fig 11.3-8 After uploading the plan data to the company's server, the surgical guide was produced by stereolithography (Dentsply Sirona). A bone-supported surgical guide was also produced by stereolithography (Simplant). In addition to the planned implant position, the guide included additional sleeves for the fixation screws (anchor pins). The implant surgery took place simultaneously with the bilateral sinus elevation.



Fig 11.3-9 A panoramic radiograph showing the situation after the bilateral sinus elevation and simultaneous implant placement.



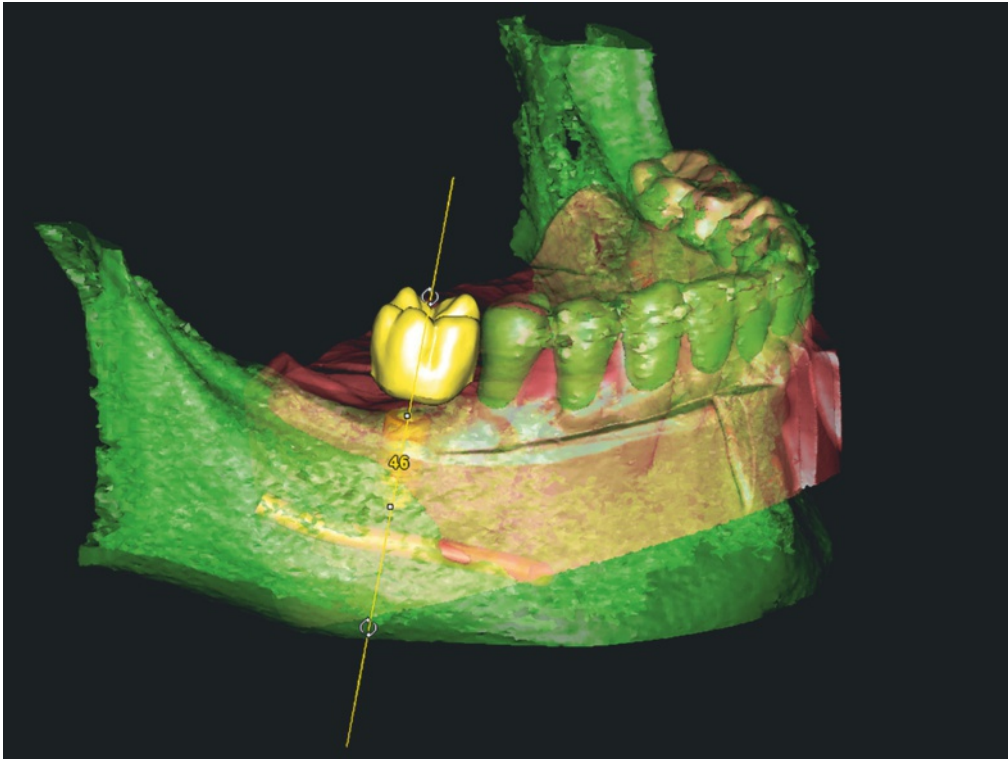
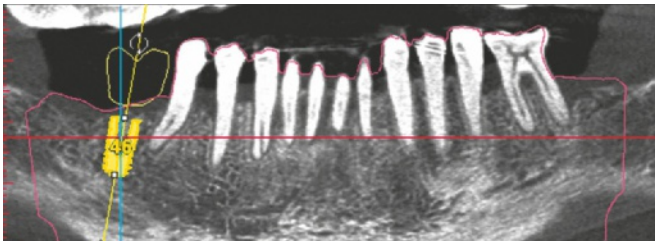


Fig 11.3-10. In the mandible, an implant-supported single crown was planned to replace tooth 46. In addition to CBCT of the mandible, the mandibular model was scanned using a desktop scanner. After importing the DICOM and Standard Tessellation Language (STL) datasets into the planning software (Simplant), superimposition (data fusion) was performed to include merged soft and hard tissue information on the computer screen. Then, the anatomical landmarks were marked (mandibular nerve, mental foramen, and so on) and a virtual tooth 46 was positioned (top). The corresponding implant was virtually planned (middle left and right) and the planning data were uploaded to the manufacturer to fabricate a surgical guide (Simplant). Then, the tooth-supported surgical guide was placed and the implant was inserted (bottom left and right).



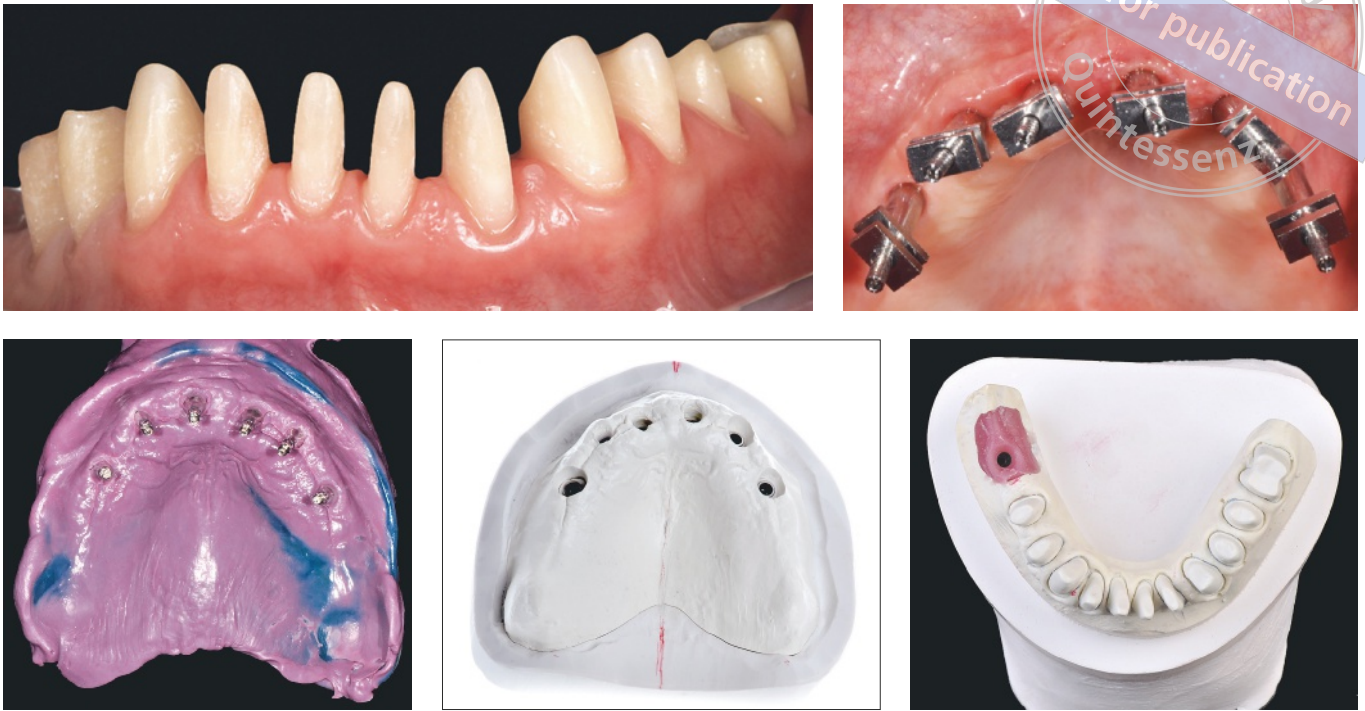


Fig 11.3-11 After a healing period of 6 months, second-stage surgery to uncover the implants in both jaws was performed. With the aid of a mock-up (not shown), the mandibular teeth were prepared (top left). Three weeks after surgery, impression copings were fixed onto the implants (top right) and conventional impressions were performed using custom-made impression trays and a polyether impression material (Impregum, 3M Espe, Seefeld, Germany; bottom left). Then, casts were poured using a type IV dental stone (lower right).

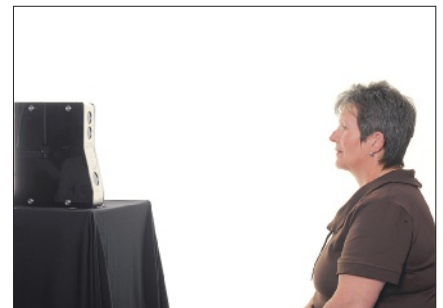
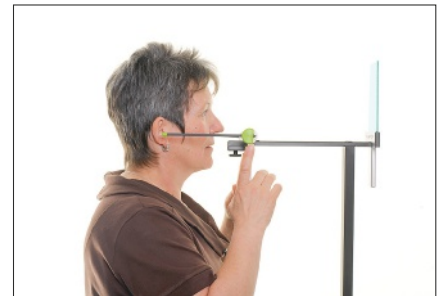
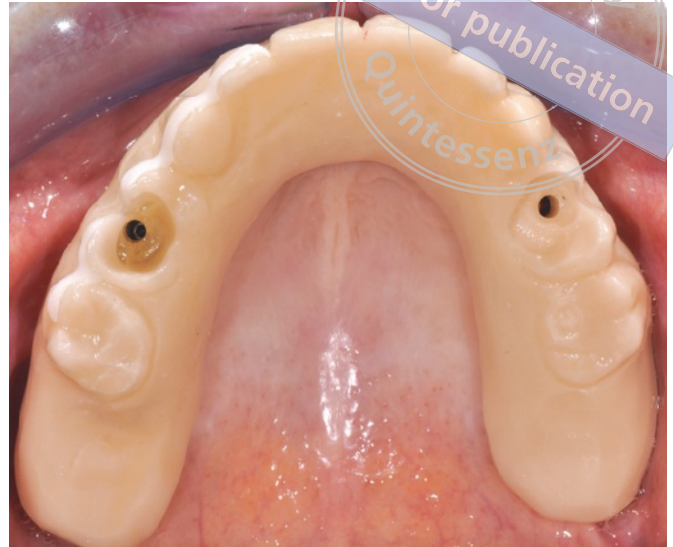


Fig 11.3-12 After pouring the casts, a tooth-form registration template was fabricated and fixed onto at least two implants in the maxilla (top left and right). As previously described, the registration of the zero position (horizontal plane), maxilla position, and the ala-tragus plane was conducted with a natural head position while the patient was standing and looking into a mirror (PlaneFinder, Zirkonzahn, Gais, Italy; middle row). During the same session, a face scanner (FaceHunter, Zirkonzahn, Gais, Italy) was used to capture the facial surface morphology as well as the corresponding relationship of the maxilla with the aid of the scan fork (bottom). The registration procedure has been described earlier in this book in Chapter 6.

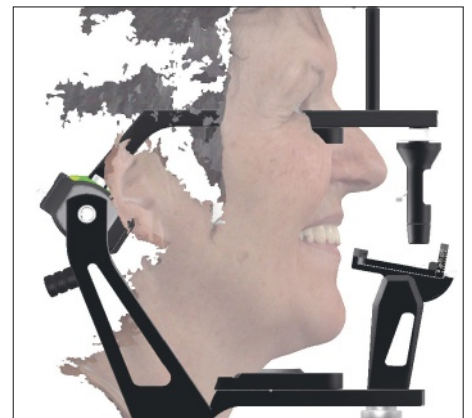
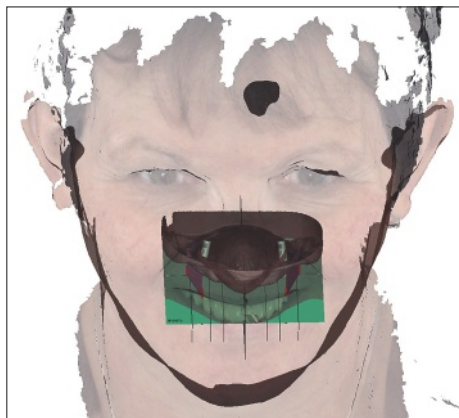
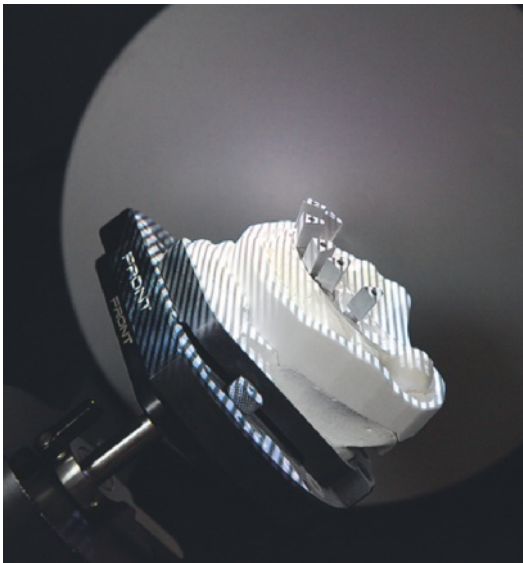
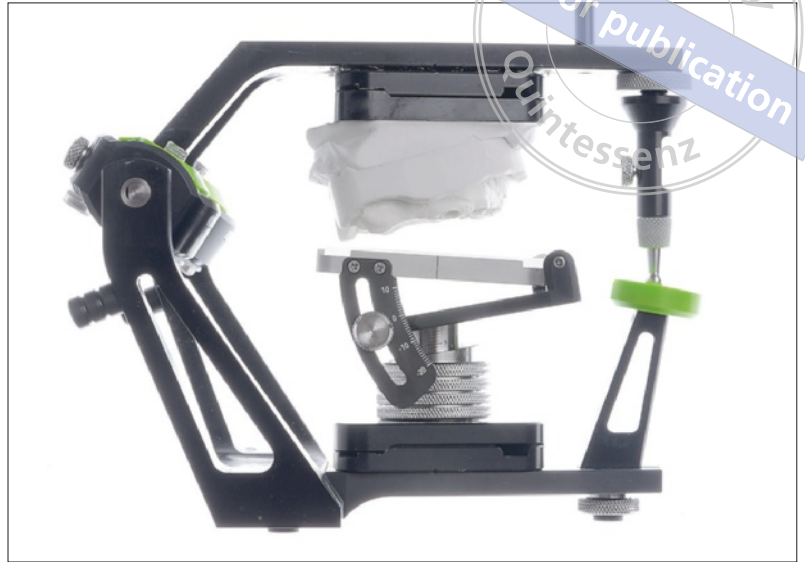


Fig 11.3-13 After the registration procedure, the casts were mounted conventionally in a semi-adjustable articulator (PS1, Zirkonzahn, Gais, Italy; top left and right). Then, the casts were scanned (separately as well as together with the articulator) in order to digitize all patient-relevant information (middle left and right). Also, data of the face scan were fused with the model scan data to add soft tissue anatomical structure information (bottom).

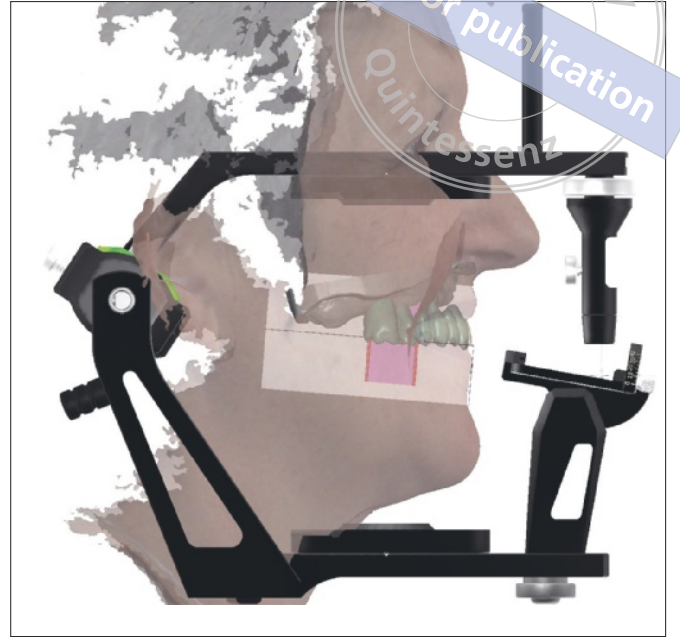
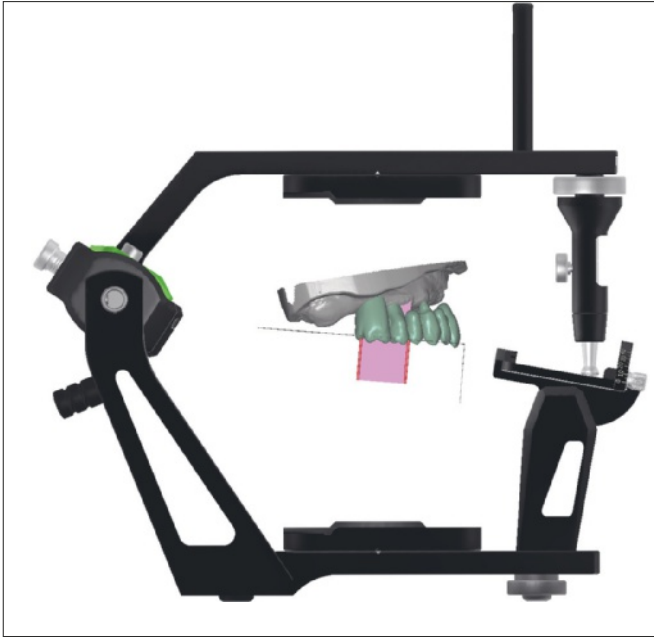


Fig 11.3-14 Following the registration and virtual mounting procedures, the lab technician performed computer-aided design (CAD) of the rehabilitation in both jaws. The integrated soft tissue information eases setting the position of the teeth and respects several parameters, such as the smile line, midline, tooth exposure at rest, and the buccal corridor (top left and right). Then, prototypes of the CAD data are milled out of a PMMA block (bottom left and right).

Fig 11.3-15 The prototypes were then adapted to the models and verified (top left and right). Further processing with the addition of a pink resin (middle left and right) enhances esthetics and provides proper lip support (compensation for lost soft and hard tissues). Then, the prototypes are tried in and verified for esthetics, phonetics, and function (bottom left and right). Modifications in tooth form, length, and orientation can be directly made on the prototypes. Should there be a need for additional modifications, a composite resin can be used and applied directly. In case of modifications, the prototypes are returned to the laboratory for scanning and implementing of changes to the improved design.



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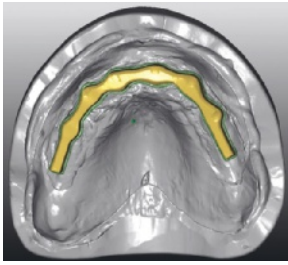


Fig 11.3-16 After implementing changes in the design of the prototypes, CAD of a bar was performed (top left). Then, the bar was milled from a titanium block (top middle) and seated onto the model (top right). A corresponding prototype fitting over the bar was subsequently milled from a PMMA block. A further housing for providing friction of the upper prosthesis was milled out of a polyetheretherketone (PEEK) material (middle left). Then, the housing was attached to the prototype using an adhesive and further processed in order to improve the esthetics (middle right). A further prototype for the mandible was milled out of a PMMA block and adapted to the upper prototype (bottom).



Fig 11.3-17 The bar and prototypes are tried onto the implants (top). If necessary, the prototypes can be delivered and used by the patient for a period of up to 2 months in order to verify esthetics, phonetics, function, and hygiene (middle). In case any changes are required, the clinician can perform these directly on the prototypes (bottom). When all parameters have been verified and the patient is satisfied, the definitive restorations can be produced. In case of modifications, the prototypes are then removed and sent to the technician for digitization and modification of the original design.

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Fig 11.3-18 After setting the final CAD, the computer-aided manufacturing (CAM) procedure can take place. The maxillary and mandibular restorations were milled out of zirconia blocks (top). Here, the design considered fully contoured restorations with space for minimal facial veneering in the anterior teeth to improve esthetics.³¹⁻³⁴ The milled restorations were further characterized by individual coloring before final sintering (middle left and right). Then, the maxillary prosthesis and single restorations in the mandible were sintered to their final state and further characterized (bottom left and right).



Fig 11.3-19 After sintering and further coloring, the veneering procedure is performed in the facial aspect of the anterior teeth in the maxillary and mandibular restorations. Further characteristics to mimic the natural tooth and gingival appearance were implemented by the lab technician (top). The milled retentive element made of PEEK was fixed into the specified housing in the prosthesis using an adhesive resin (Multilink Hybrid Abutment, Ivoclar Vivadent, Schaan, Liechtenstein) (middle left and right). Should the retention deteriorate over the service period, further retentive elements can be easily milled out of the same material and used to replace the existing element (bottom left and right).



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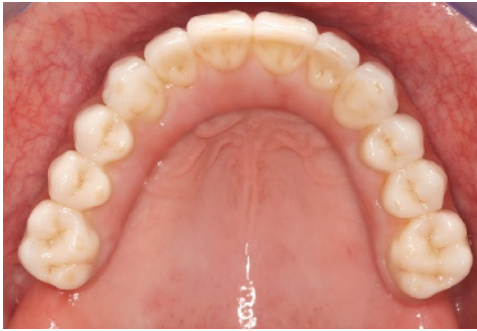


Fig 11.3-20 The bar in the maxilla as well as the implant abutment crown was delivered onto the implants by means of screw retention using a torque control wrench. The single crowns were cemented using a resin cement (Multilink Automix; Ivoclar Vivadent, Schaan, Liechtenstein). Occlusal views show the situation directly after delivery in both jaws (top left and right). The anterior view reveals the esthetic integration of the restorations in both jaws (bottom).



Fig 11.3-21 A panoramic radiograph after delivery showed proper integration of the implants and rehabilitation.

Fig 11.3-22 The esthetic outcome of the final restorations corresponded to the patient's wishes and expectations. The facial harmony and esthetic integration of the delivered restorations reflected the treatment's success.





References

1. Muller F. Interventions for edentate elders – what is the evidence? *Gerodontology* 2014;31 Suppl 1:44–51.
2. Strassburger C, Kerschbaum T, Heydecke G. Influence of implant and conventional prostheses on satisfaction and quality of life: a literature review. Part 2: qualitative analysis and evaluation of the studies. *Int J Prosthodont* 2006;19:339–348.
3. Vogel R, Smith-Palmer J, Valentine W. Evaluating the health economic implications and cost-effectiveness of dental implants: a literature review. *Int J Oral Maxillofac Implants* 2013;28:343–356.
4. White GS. Treatment of the edentulous patient. *Oral Maxillofac Surg Clin North Am* 2015;27:265–272.
5. Gallucci GO, Doughtie CB, Hwang JW, Fiorellini JP, Weber HP. Five-year results of fixed implant-supported rehabilitations with distal cantilevers for the edentulous mandible. *Clin Oral Implants Res* 2009;20:601–607.
6. Heydecke G, Zwahlen M, Nicol A, et al. What is the optimal number of implants for fixed reconstructions: a systematic review. *Clin Oral Implants Res* 2012;23 Suppl 6:217–228.
7. Mericske-Stern R, Worni A. Optimal number of oral implants for fixed reconstructions: a review of the literature. *Eur J Oral Implantol* 2014;7 Suppl 2:S133–S153.
8. Pjetursson BE, Thoma D, Jung R, Zwahlen M, Zembic A. A systematic review of the survival and complication rates of implant-supported fixed dental prostheses (FDPs) after a mean observation period of at least 5 years. *Clin Oral Implants Res* 2012;23 Suppl 6:22–38.
9. Bryant SR, MacDonald-Jankowski D, Kim K. Does the type of implant prosthesis affect outcomes for the completely edentulous arch? *Int J Oral Maxillofac Implants* 2007;22 Suppl:117–139.
10. Heydecke G, Boudrias P, Awad MA, De Albuquerque RF, Lund JP, Feine JS. Within-subject comparisons of maxillary fixed and removable implant prostheses: patient satisfaction and choice of prosthesis. *Clin Oral Implants Res* 2003;14:125–130.
11. Jemt T, Lekholm U. Implant treatment in edentulous maxillae: a 5-year follow-up report on patients with different degrees of jaw resorption. *Int J Oral Maxillofac Implants* 1995;10:303–311.
12. Jung RE, Zembic A, Pjetursson BE, Zwahlen M, Thoma DS. Systematic review of the survival rate and the incidence of biological, technical, and aesthetic complications of single crowns on implants reported in longitudinal studies with a mean follow-up of 5 years. *Clin Oral Implants Res* 2012;23 Suppl 6:2–21.
13. Kiener P, Oetterli M, Mericske E, Mericske-Stern R. Effectiveness of maxillary overdentures supported by implants: maintenance and prosthetic complications. *Int J Prosthodont* 2001;14:133–140.
14. Mericske-Stern R, Oetterli M, Kiener P, Mericske E. A follow-up study of maxillary implants supporting an overdenture: clinical and radiographic results. *Int J Oral Maxillofac Implants* 2002;17:678–686.
15. Pjetursson BE, Bragger U, Lang NP, Zwahlen M. Comparison of survival and complication rates of tooth-supported fixed dental prostheses (FDPs) and implant-supported FDPs and single crowns (SCs). *Clin Oral Implants Res* 2007;18 Suppl 3:97–113.
16. Pjetursson BE, Sailer I, Zwahlen M, Hammerle CH. A systematic review of the survival and complication rates of all-ceramic and metal-ceramic reconstructions after an observation period of at least 3 years. Part I: single crowns. *Clin Oral Implants Res* 2007;18 Suppl 3:73–85.
17. Sailer I, Muhlemann S, Zwahlen M, Hammerle CH, Schneider D. Cemented and screw-retained implant reconstructions: a systematic review of the survival and complication rates. *Clin Oral Implants Res* 2012;23 Suppl 6:163–201.
18. Slot W, Raghoobar GM, Vissink A, Huddleston Slater JJ, Meijer HJ. A systematic review of implant-supported maxillary overdentures after a mean observation period of at least 1 year. *J Clin Periodontol* 2010;37:98–110.
19. Chiapasco M, Casentini P, Zaniboni M. Bone augmentation procedures in implant dentistry. *Int J Oral Maxillofac Implants* 2009;24 Suppl:237–259.
20. Pjetursson BE, Tan WC, Zwahlen M, Lang NP. A systematic review of the success of sinus floor elevation and survival of implants inserted in combination with sinus floor elevation. *J Clin Periodontol* 2008;35:216–240.
21. Sivolella S, Bressan E, Gnocco E, Berengo M, Favero GA. Maxillary sinus augmentation with bovine bone and simultaneous dental implant placement in conditions of severe alveolar atrophy: a retrospective analysis of a consecutively treated case series. *Quintessence Int* 2011;42:851–862.
22. Tan WC, Lang NP, Zwahlen M, Pjetursson BE. A systematic review of the success of sinus floor elevation and survival of implants inserted in combination with sinus floor elevation. Part II: transalveolar technique. *J Clin Periodontol* 2008;35:241–254.

23. Tuna T, Yorgidis M, Strub JR. Prognosis of implants and fixed restorations after lateral sinus elevation: a literature review. *J Oral Rehabil* 2012;39:226–238.
24. Rocuzzo M, Bonino F, Gaudio L, Zwahlen M, Meijer HJ. What is the optimal number of implants for removable reconstructions? A systematic review on implant-supported overdentures. *Clin Oral Implants Res* 2012;23 Suppl 6:229–237.
25. Cortellini P, Tonetti MS, Lang NP. The simplified papilla preservation flap in the regenerative treatment of deep intrabony defects: clinical outcomes and postoperative morbidity. *J Periodontol* 2001;72:1702–1712.
26. Forabosco A, Grandi T, Cotti B. The importance of splinting of teeth in the therapy of periodontitis. *Minerva Stomatol* 2006;55:87–97.
27. Kumbuloglu O, Saracoglu A, Ozcan M. Pilot study of unidirectional E-glass fibre-reinforced composite resin splints: up to 4.5-year clinical follow-up. *J Dent* 2011;39:871–877.
28. Lindhe J, Nyman S. The role of occlusion in periodontal disease and the biological rationale for splinting in treatment of periodontitis. *Oral Sci Rev* 1977;10:11–43.
29. Nyman SR, Lang NP. Tooth mobility and the biological rationale for splinting teeth. *Periodontology* 2000 1994;4:15–22.
30. Sekhar LC, Koganti VP, Shankar BR, Gopinath A. A comparative study of temporary splints: bonded polyethylene fiber reinforcement ribbon and stainless steel wire and composite resin splint in the treatment of chronic periodontitis. *J Contemp Dent Pract* 2011;12:343–349.
31. Limmer B, Sanders AE, Reside G, Cooper LF. Complications and patient-centered outcomes with an implant-supported monolithic zirconia fixed dental prosthesis: 1-year results. *J Prosthodont* 2014;23:267–275.
32. Rojas Vizcaya F. Retrospective 2- to 7-year follow-up study of 20 double full-arch implant-supported monolithic zirconia fixed prostheses: measurements and recommendations for optimal design. *J Prosthodont* 2016;27:501–508.
33. Sulaiman TA, Abdulmajeed AA, Donovan TE, Cooper LF, Walter R. Fracture rate of monolithic zirconia restorations up to 5 years: a dental laboratory survey. *J Prosthet Dent* 2016;116:436–439.
34. Venezia P, Torsello F, Cavalcanti R, D'Amato S. Retrospective analysis of 26 complete-arch implant-supported monolithic zirconia prostheses with feldspathic porcelain veneering limited to the facial surface. *J Prosthet Dent* 2015;114:506–512.



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