The complete digital workflow in interdisciplinary dentistry

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Abstract

New digital tools facilitating data acquisition, team communication, computer-assisted diagnostics, and treatment planning as well as the design and fabrication of restorations, guides, stents and devices in general have fundamentally altered key clinical and laboratory steps. The number of new technologies and the amount of new equipment used today to acquire patient data, the software to manipulate this data, and the machines to manufacture devices from it drastically increases all the time, as do the challenges of integrating these systems into a feasible, realistic, and practical workflow. Creating a simple complete digital workflow is key to taking advantage of these digital opportunities and offering their benefits to all patients. Making digital workflows the routine rather than the exception is fundamentally important in order to grow a dental practice in this new environment. This article presents a new complete digital workflow that changes and improves the process of treating a comprehensive case from diagnostics to execution and maintenance.
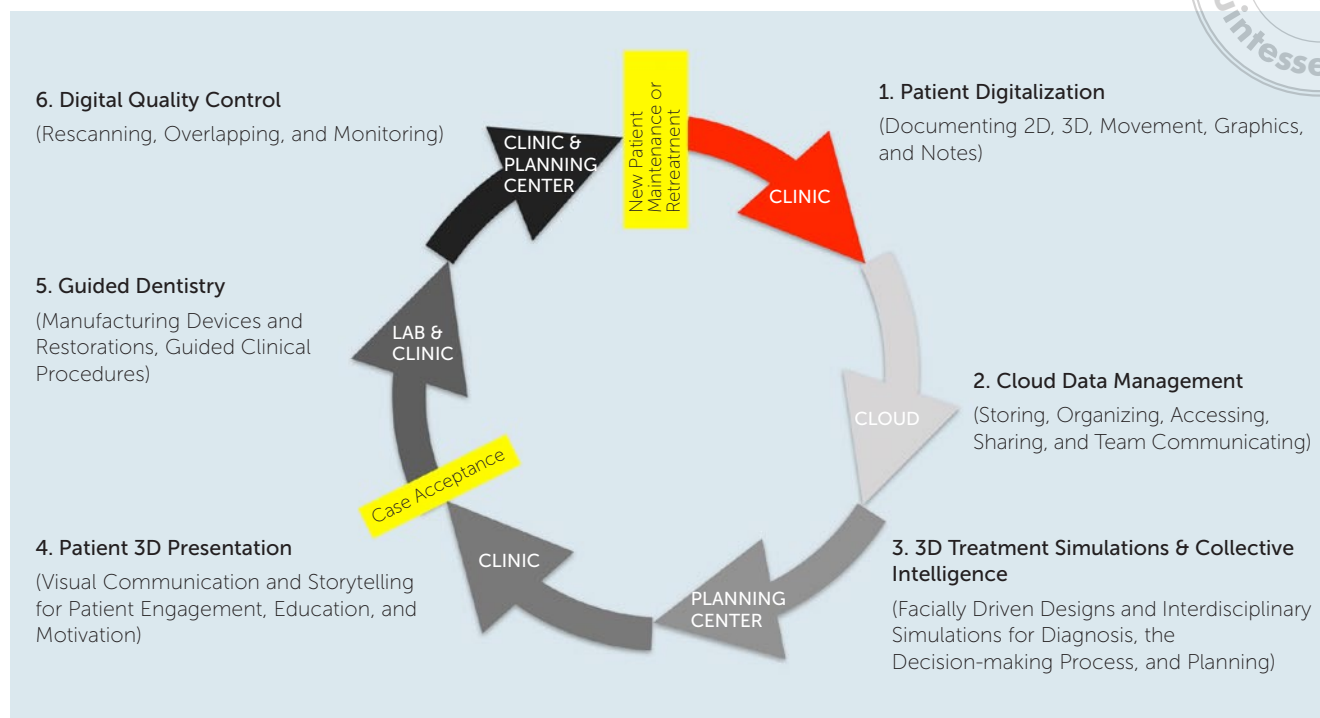*(Int J Esthet Dent 2021;16:2–17)*

6. Digital Quality Control
(Rescanning, Overlapping, and Monitoring)

CLINIC & PLANNING CENTER

New Patient Maintenance or Retreatment

CLINIC

1. Patient Digitalization
(Documenting 2D, 3D, Movement, Graphics, and Notes)

5. Guided Dentistry
(Manufacturing Devices and Restorations, Guided Clinical Procedures)

LAB & CLINIC

CLOUD

2. Cloud Data Management
(Storing, Organizing, Accessing, Sharing, and Team Communicating)

Case Acceptance

CLINIC

PLANNING CENTER

4. Patient 3D Presentation
(Visual Communication and Storytelling for Patient Engagement, Education, and Motivation)

3. 3D Treatment Simulations & Collective Intelligence
(Facially Driven Designs and Interdisciplinary Simulations for Diagnosis, the Decision-making Process, and Planning)

Fig 1 The six steps of the new complete digital workflow.

Introduction

The purpose of this article is to present the concepts involved in the six key steps that comprise a complete digital dental concept and workflow (Fig 1).

In the dental laboratory, CAD/CAM systems that include optical or mechanical scans of a cast, digital restoration design software, and a CAM system – either in the laboratory or at a centralized milling center – have become standard over the last few decades.[2] There are still significant opportunities to further establish and integrate digital tools in the dental practice and in interdisciplinary treatment. For example, digital smile design tools and software have undergone a significant evolution and are now far more advanced than traditional esthetic evaluation and treatment guidelines, which are typically based on 2D measurements. One key aspect is the ability to include 3D analyses and models into the smile assessment and design.[3-5]

Intra- and extraoral optical scanners enable the 3D evaluation of all oral and facial structures, as does digital radiography such as CBCT, while specific computer programs and software tools facilitate the digital planning and visualization of anticipated esthetic outcomes to accurately plan and execute multidisciplinary treatment.[6]

Digital smile analysis and design was first described in the early 2000s,[7-9] leading to the development of several computer programs for esthetic analyis.[6] In 2008, the first fully facially guided digital smile design protocol was developed.[10] Merging facial, extraoral, and intraoral photographs with 3D digital models facilitated the application of a completely digital workflow to evaluate esthetic parameters and treatment plan smiles in 3D.[11] Since then, digital technologies in dentistry have progressed in a way that few

people could have predicted. These technologies enable the establishment of truly esthetic outcomes through algorithm libraries of natural teeth and smiles, which are superior to hand-built wax-ups and setups because they do not depend on individual skills and subjective interpretation.[12]

All the various digital tools, however, are limited or even useless unless they are integrated into a complete and comprehensive digital concept and workflow. This article describes a new and complete digital workflow that can be applied in the dental practice, and discusses the impact of this workflow on interdisciplinary dental treatment. Our goals were to identify and demonstrate current trends, share our visions for the future, and create an understanding of these visions, even though some of the digital tools may not as yet be perfect. Despite some current limitations, which should be resolved sooner or later, digital workflows already provide excellent, more predictable, and reproducible outcomes compared with analog techniques.

The six steps of the new complete digital workflow

Step 1: Patient Digitalization

In the new complete digital workflow, traditional and analog patient documentation is replaced by Patient Digitalization (Fig 2). The integration of a 3D face scan with the CBCT scan, STL files, virtual articulator as well as face and jaw movements allow for a significantly more accurate analysis and visualization of all orofacial issues as well as functional, structural, and esthetic aspects, including the temporomandibular joint (TMJ), airway, and other anatomical structures.[13]

In the past, clinicians relied almost exclusively on their subjective and sometimes incorrect clinical evaluation and judgment. This process was hindered by limited
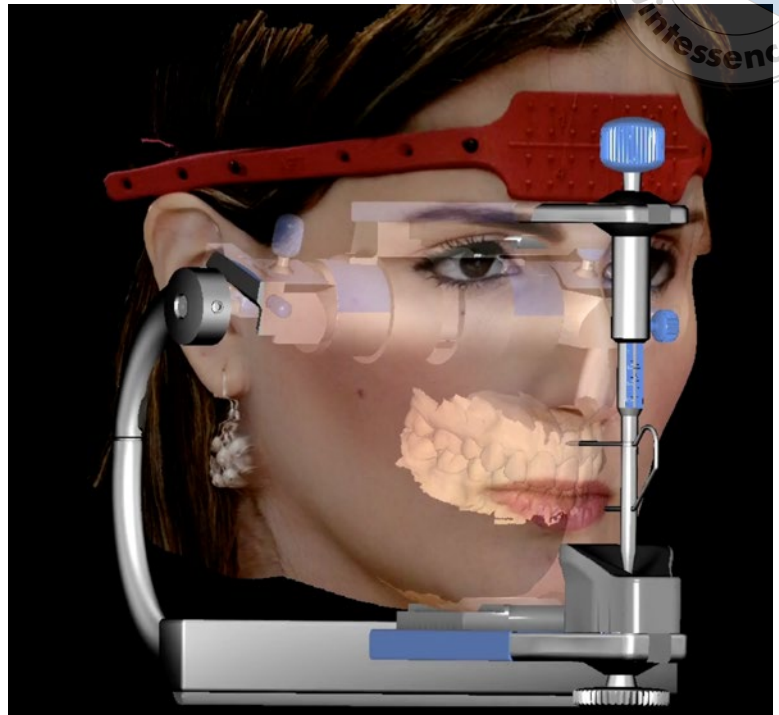

Fig 2 Patient Digitalization with a 3D face scan integrated with the CBCT scan, STL files, virtual articulator as well as face and jaw movements.

knowledge and understanding of facial and dental esthetics that overly relied on written information, combined with the inaccuracies and distortions of analog procedures such as impression making, facebow transfer, interocclusal records, and analog articulators. In contrast, Patient Digitization can greatly improve visualization, evaluation, and diagnosis. In addition, these steps can be carried out on the computer even without the patient being present, saving valuable chair time. Adding a full-skull CBCT scan during the first appointment allows for a thorough evaluation of structures and possible pathologies, including TMJ, airway, and facial analyses, that cannot be detected otherwise. Instead of proposing a CBCT scan only when an issue is suspected, or only performing a sectional CBCT examination, routine use of full-skull CBCT imaging may have a significant impact on patients' well-being, since individual anatomical

features and possible pathologies of the maxillofacial complex that cannot be detected otherwise can be evaluated and identified, possibly at an early stage. While radiation exposure for a full-skull CBCT scan is greater than for a sectional one, overall exposure with current CBCT machines has been significantly reduced compared with earlier models and traditional computed tomography machines.[14]

With the Patient Digitization tools available today:

- Intraoral scanners (IOSs) eliminate the need for intraoral photographs and impressions.
- Face scans eliminate the need for extraoral photographs and provide a 3D image.
- Virtual articulators, overlapped with face photographs or scans, eliminate the need for analog facebows and articulators.

The required digital files for complete Patient Digitalization are:

- 2D digital files
  - Static images
    - Photographs (extra- and intraoral)
    - Radiographs
    - Panoramic radiographs
  - Dynamic images
    - Videos (technical, phonetics, and personality)
- 3D digital files
  - Face scans (at rest and while smiling)
  - Intraoral scans (maxilla, mandible, and interocclusal records)
  - CBCT scans
- Movements
  - Facial movements
  - Intraoral mandibular movements
- Texts/graphics
  - Medical history/questionnaires
  - Dental charts
  - Periodontal charts
  - Occlusal charts

Various digital file formats from the different digital tools (CBCT machine, IOS, face scanner, etc) may pose some challenges when assembling the digitalized patient and possibly lead to distortions. However, the merging and overlapping of such files is becoming significantly simpler, especially with the application of artificial intelligence (AI) tools. Technologies to increase precision and accuracy in the digital workflow are constantly improving and may already supersede analog steps, eg, taking into account interocclusal records, facebow registration and transfer, and the mounting of models in an articulator.

Step 2: Cloud Dentistry

Another great benefit of the complete digital workflow is the concept of Cloud Dentistry. Since the patient is digitalized and all documentation is available as digital files, the information can be immediately stored in the cloud with specifically designed software and in formats that are compliant with local patient information privacy laws.

One major challenge for developing interdisciplinary treatment plans for every patient is the lack of time to brainstorm and discuss treatment options with other experts before making key decisions. In today's world, talking to experts and team members on the phone or scheduling in-person meetings is often not practical, feasible or financially sensible. Consequently, and since creating a customized treatment plan for every patient in such manner is extremely time consuming, many dentists find themselves developing comprehensive treatment plans on their own and without the valuable input of other experts. However, developing a treatment plan based on only one opinion and without specialists' participation may, especially in complex cases, be very limiting, and may not fully address all of the patient's conditions and needs. Interdisciplinary treatment planning requires a decision-making process based on a team

Fig 3 Traditional in-person treatment planning meetings are replaced by a digital Asynchronous Communication system that allows team communication from different places and at different times.

approach. Even when specialists and team members are working in the same building, conflicting schedules may prevent in-person meetings and direct communication. In addition, even simple consultations on a specific patient situation can be difficult to manage within a reasonable timeframe.

The solution to these challenges is a system that allows for so-called Asynchronous Communication (Fig 3), ie, interacting with several people who are neither in the same place nor available at the same time. This concept is derived from social media, where users can send a message to several people who can interact and comment whenever it is convenient for them to do so. It allows for information transfer and exchange, so team members can actively participate even when their schedules or locations do not coincide in time or space. In this sense, it follows the collective intelligence (CI) concept, which is shared or group intelligence that derives from the collaboration, collective efforts, and competition of many individuals. The first dental software that attempted to provide a platform for Asynchronous Communication was the DSDApp (by Coachman). The software platform Smile Cloud (ADN3D Biotech SRL) offers a similar solution.

The advantages of consolidating all patient data in the cloud are:

- Overcome the greatest challenge to interdisciplinary treatment planning, which is the inability to discuss a patient case as a team due to time and location constraints.
- Improve quality of evaluations, diagnoses, and treatment plans through interaction and collaboration of team members and top specialists from any place in the world.
- Eliminate the need for in-person meetings.
- Accelerate information flow and improve collaboration with specialists, dental laboratories, 3D planning and imaging centers, and others.
- Allow patients to participate and stay informed about the process to the extent determined by the provider.

Implementation of the Asynchronous Communication concept is only possible through Patient Digitalization and Cloud Dentistry. It is key that all patient information is available online (in the cloud), and that all team members are connected and interacting through a common communication channel (Fig 4).

GENERATING DATA

Analog and Digital Systems

Digital allows more and deeper information from the patient

a

SAVING & ORGANIZING DATA

Protected Cloud Platform

Digital allows better management of information

PROCESSING DATA

Sharing, Accessing, and Interacting

Dentist 1
Dentist 2
Dentist 3
Staff
Planning center
Aligner company
Laboratory
etc

Digital allows asynchronous communication and collective intelligence systematically

Fig 4a and b
The digitalized patient information is available online (cloud) with all team members connected and interacting through the Asynchronous Communication system, creating more efficient and effective communication and making better use of the collective intelligence.

EFFICIENT & EFFECTIVE COMMUNICATION

Collaborating from Different Places and Different Time Zones

Planning Center

Laboratory

Other Services

Dentist 2

Cloud

Dentist 1

b

Digital allows better decision making as a team for every single patient

Step 3: Virtual Treatment Simulation

The interdisciplinary communication and collaboration of all connected specialists and participants (Asynchronous Communication) starts after the patient is completely digitalized and the uploaded information is readily available in the cloud. The exchange of ideas and suggestions will facilitate the formulation of alternative treatment plans.

The next step in the complete digital workflow is to test drive the various alternatives and possibilities with 3D simulations. The idea is to 'make mistakes on the computer to reduce the mistakes in the mouth.' It is similar to an airplane pilot who will simulate numerous flights before

flying a real plane with actual people on board.

As the team of specialists suggests treatment options, a 3D software expert team (Planning Center) will translate these ideas into simulations to visualize prospective outcomes and their impact. It is critical not to draw conclusions too quickly or make decisions based only on clinical examinations and conventional documentation, but to allow the 3D simulations to improve the understanding of the impact of possible treatment options and procedures. A software system that allows for all types of simulations on the same platform and at the same time is necessary to enable this. It should use the face as a starting point to make it *facially driven and interdisciplinarily connected*. This may seem obvious, but until recently, dental and smile design software systems were not facially driven and did not allow for simultaneous interdisciplinary simulations. Software programs offered by various manufacturers, specialties, and service providers, eg, Invisalign (Align Technology), Cerec (Dentsply Sirona), Dolphin (Patterson Dental), and NobelClinician (Nobel Biocare), were not connected or compatible. Since the specialties were not connected, the impact of one procedure on another could not be evaluated, and interdisciplinary digital simulations were not possible. Moreover, most of the original dental software programs concentrated on teeth. They did not use the face as the starting point, so can be considered neither facially driven nor interdisciplinary. Common dental software programs focused only on the treatment execution of dentistry and not on the planning. However, the most powerful part of digital dentistry is that it can assist clinicians with the most difficult aspects of dentistry: diagnosis, decision making, risk assessment, design, and treatment planning. Unfortunately, none of the common software programs were

originally developed to assist with these aspects; they only allowed clinicians to take advantage of these digital tools after major treatment decisions had already been made.

Facially driven and interdisciplinarily integrated software platforms are the keys for modern digital dentistry. The new complete digital workflow provides the dentist with the opportunity to translate all treatment options proposed by the team into 3D simulations, either through the dental office acquiring all the necessary technology and training staff members to manage these technologies or, in a more realistic scenario, by dentists outsourcing the workup to a Planning Center that translates proposed treatment plans and procedures into simulations, allowing any dentist to take advantage of this technology without worrying about financial investments and learning curves. These simulations connect the clinical treatment planning team with the Planning Center through the cloud, which is only possible if all patients are digitalized. Consequently, the connection of all three initial steps of the modern digital workflow are: Patient Digitalization › Cloud Dentistry/Asynchronous Communication › Virtual Treatment Simulation/Planning Center Outsourcing.

Today, any treatment plan can be simulated, which provides a very powerful understanding of the impact of the planned procedure from an interdisciplinary perspective. From simple to complex, from single procedure to combined procedures, the facially driven smile design (Figs 5 and 6) shows a restorative plan, which determines and guides an orthodontic simulation that not only moves the crowns of teeth but also demonstrates root movement and its impact on the surrounding bone.

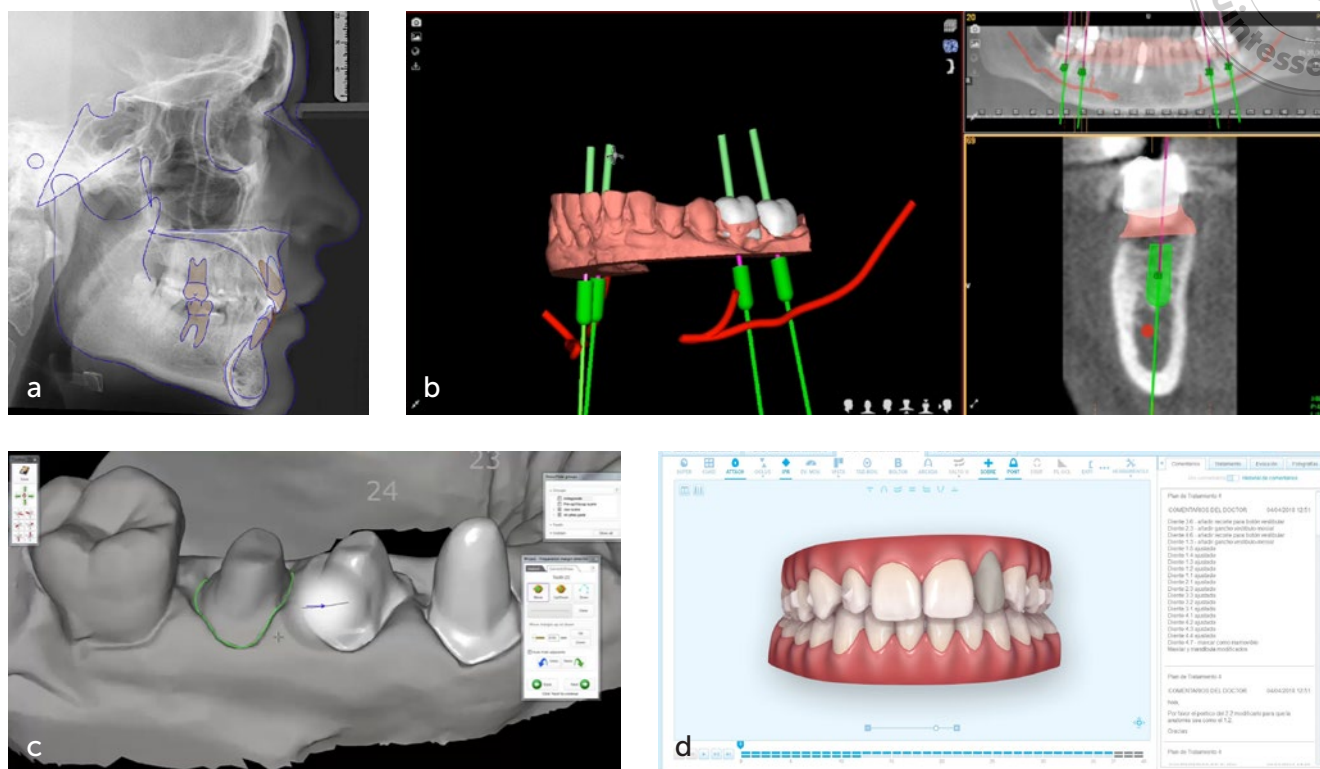There are two key timeframes when using 3D software in dentistry:

Fig 5a to d Initially, dental software did not use the face as the starting point. It was typically fragmented and did not have interdisciplinary connectedness. It was therefore unable to provide combined simulations and comprehensive treatment planning.
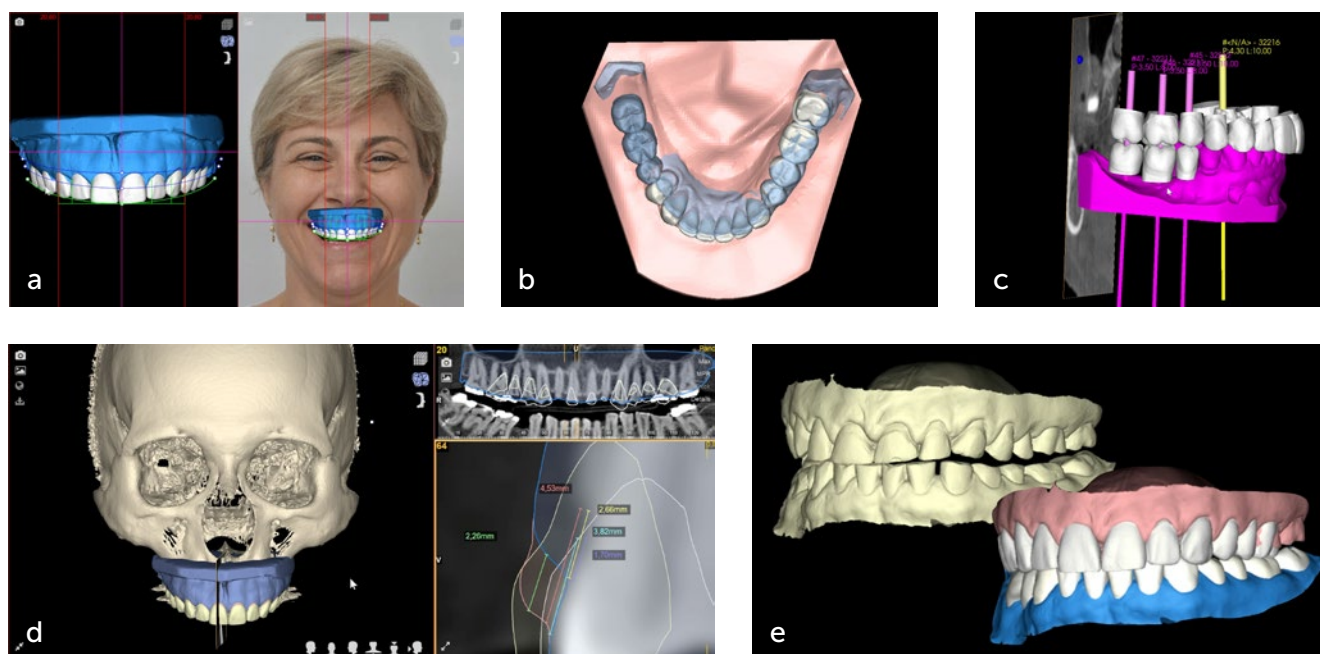

Fig 6 Example of a case planned using interdisciplinary facially driven software, where the starting point is the ideal initial functional and esthetic smile design (a). Then, the orthodontic simulation (b), implant planning (c), periodontic analysis (d), and restorative design (e) are all planned based on the initial smile design and simulated together to allow for the evaluation of the impact of one procedure on another.
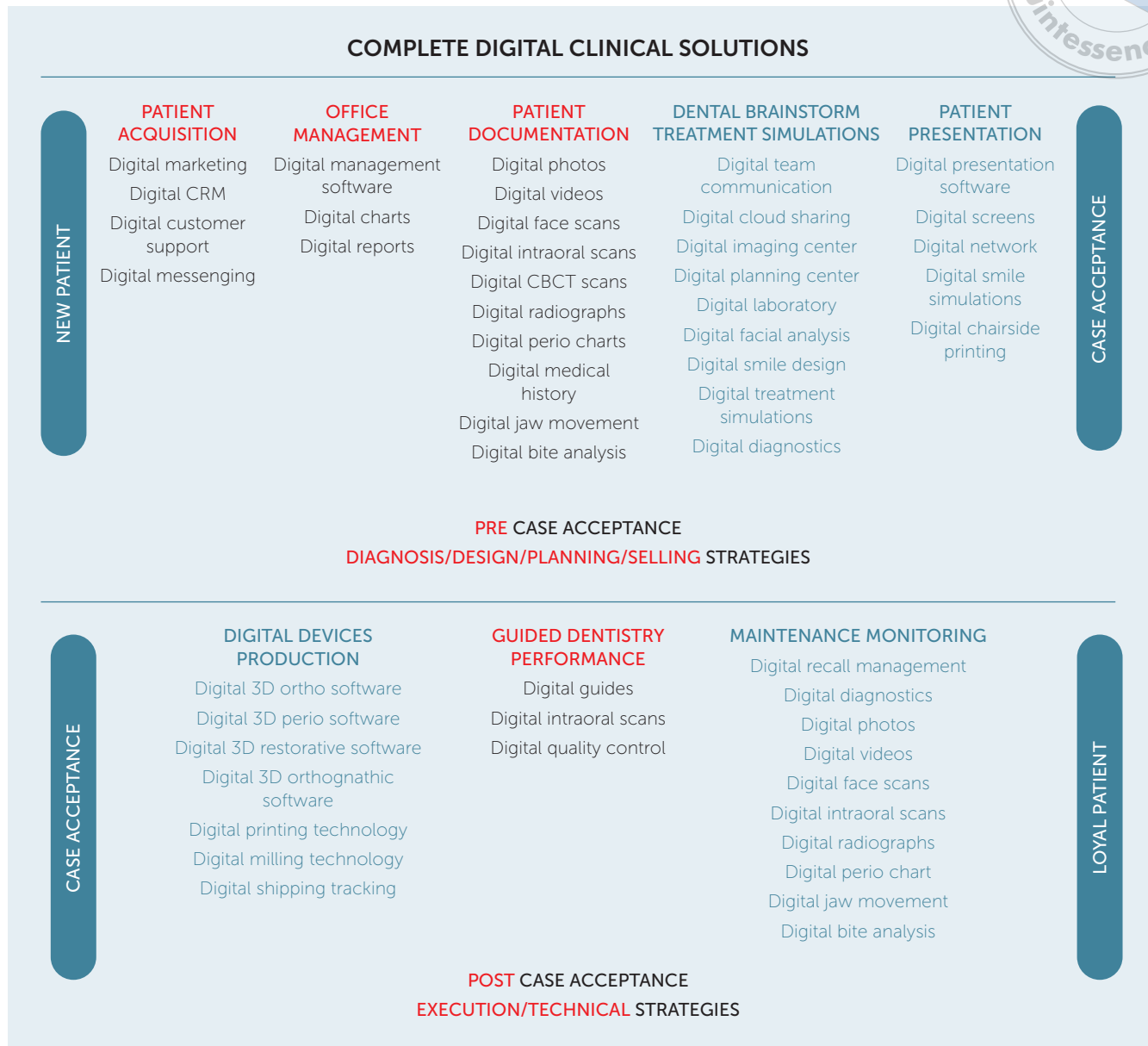
COMPLETE DIGITAL CLINICAL SOLUTIONS

NEW PATIENT

PATIENT ACQUISITION	OFFICE MANAGEMENT	PATIENT DOCUMENTATION	DENTAL BRAINSTORM TREATMENT SIMULATIONS	PATIENT PRESENTATION
Digital marketing	Digital management software	Digital photos	Digital team communication	Digital presentation software
Digital CRM	Digital charts	Digital videos	Digital cloud sharing	Digital screens
Digital customer support	Digital reports	Digital face scans	Digital imaging center	Digital network
Digital messenging		Digital intraoral scans	Digital planning center	Digital smile simulations
		Digital CBCT scans	Digital laboratory	Digital chairside printing
		Digital radiographs	Digital facial analysis	
		Digital perio charts	Digital smile design	
		Digital medical history	Digital treatment simulations	
		Digital jaw movement	Digital diagnostics	
		Digital bite analysis		

CASE ACCEPTANCE

PRE CASE ACCEPTANCE
DIAGNOSIS/DESIGN/PLANNING/SELLING STRATEGIES

CASE ACCEPTANCE

DIGITAL DEVICES PRODUCTION	GUIDED DENTISTRY PERFORMANCE	MAINTENANCE MONITORING
Digital 3D ortho software	Digital guides	Digital recall management
Digital 3D perio software	Digital intraoral scans	Digital diagnostics
Digital 3D restorative software	Digital quality control	Digital photos
Digital 3D orthognathic software		Digital videos
Digital printing technology		Digital face scans
Digital milling technology		Digital intraoral scans
Digital shipping tracking		Digital radiographs
		Digital perio chart
		Digital jaw movement
		Digital bite analysis

LOYAL PATIENT

POST CASE ACCEPTANCE
EXECUTION/TECHNICAL STRATEGIES

Fig 7   Key steps in the complete digital clinic that involve technology. Blue sections indicate steps that require 3D software.

1. *Before case acceptance:* for diagnostics, interdisciplinary treatment planning, and patient presentations.
2. *After case acceptance:* to design and fabricate specific guides, devices, aligners, and restorations to perform guided clinical procedures (Fig 7).

For the first key timeframe (before case acceptance), facially driven and interdisciplinarily integrated software is required. In the past, 3D technology was only geared toward the second key timeframe (after case acceptance). The face was not needed, since facial analysis and smile design were

Fig 8 Patient treatment plan presentation should take place in a sophisticated presentation room with all technologies readily available for improved communication, education, and motivation.

already determined. Similarly, interdisciplinary integration was missing, since diagnosis, planning, and treatment selection had already been completed beforehand. However, these now obsolete concepts did not recognize some of the greatest advantages and most powerful features of 3D technologies with respect to diagnostics and treatment planning.

Step 4: Digital Patient Presentation and Case Acceptance

The next step of the workflow is the presentation of the treatment plan to the patient. After all ideas have been simulated and Asynchronous Communication has allowed the team to evaluate them and define an ideal treatment plan, the next critical step is to get the patient involved. Technology can play a key role in educating and motivating the patient. Visual communication is the best way to communicate and make people

embrace an idea. It is very important that the treatment plan presenter understands how to use visual communication strategies to engage the patient, create awareness, and ultimately receive case acceptance. All treatment simulations performed before and used to define the treatment plan will now become extremely powerful to educate the patient (Fig 8).

Presenting treatment plans and anticipated procedures to the patient can be outlined in four steps that form part of a journey and which should be executed in a specific sequence (Fig 9):

1. The Emotional Journey
This first step includes the smile design process and motivational mock-up. Technology is used to engage the patient emotionally by creating the vision of a possible future smile that can have a significant impact on the patient's life. This will 'deprogram' the mindset of patients regarding dentistry, which is usually extremely negative, and will 'rewire' them with a positive and exciting vision of how dentistry can change their lives for the better by regaining or improving an attractive and confident smile. The Emotional Journey is implemented through virtual smile simulations, a real motivational mock-up experience (with 3D design software and printing technology) as well as visual presentation skills and technologies such as 'before' and 'after' images, scans, personal device apps, technologies, and others.

The Emotional Journey as a first step is not only related to esthetic cases. Emotional communication strategies are about gaining the patient's trust and empathy, creating a rapport or link, and starting a relationship. Patient cases that involve esthetics should also involve an emotional link between the patient and the possible future smile. Basic psychology principles demonstrate that for any type of relationship, one first needs to gain 'emotional credits' with the other
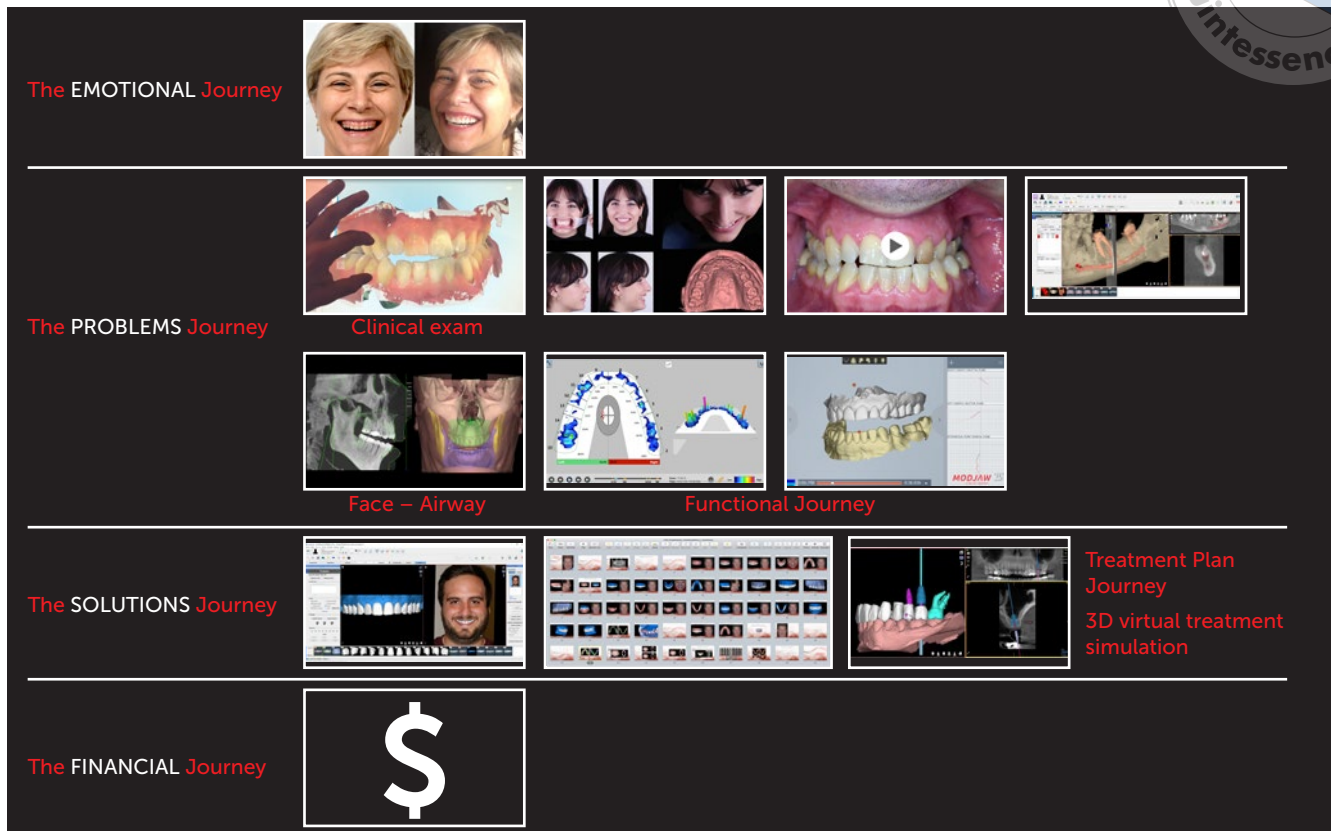
Fig 9 The four journeys of the treatment plan presentation.

person before engaging in more rational aspects to ultimately increase the value of any technical explanations. It is, therefore, recommended to first create an emotional link with the patient and later discuss technicalities, problems, solutions as well as financial and personal implications.

2. The Problems Journey
Digital technologies are applied to take the patient on a profound journey to demonstrate all the clinical findings and areas of concern as well as the impact of not treating these issues. The clinician must understand the importance of the Problems Journey and the reasons for explaining the issues before explaining the solutions. It is difficult for a patient to value a solution before visually experiencing and understanding the problems at hand and the possible consequences that may occur if they are not resolved. Since dentists already understand the problems and the solutions, a very common mistake that many of them make is to tend to quickly move to explaining the solutions without properly clarifying the concerns.

The Problems Journey is best performed with digital tools that provide visual information and explanations. Among the most powerful tools at this point are IOSs with true colors, combined with other digital images generated by cameras, mobile phones, panoramic and other radiographic images, 3D CBCT scans, facial scans, videos, and others. New scanning technologies, eg, near infrared and ultrasound, have tremendous

added value since they can detect, document, and track certain pathologies such as caries and, besides the ensuing clinical benefits, can provide meaningful assistance with patient education.

3. The Solutions Journey

In this step, all treatment simulations are presented to the patient. After the emotional connection has been made and a clear understanding of the problems has been reached, the patient is able to give value to the suggested solutions. The images generated by the 3D treatment simulation software (Asynchronous Communication) are now used to engage the patient with the solutions toward a full understanding of the reason and benefit of each treatment procedure.

4. The Financial Journey

Once the solutions are fully understood, the patient is ready to consider and appreciate the costs involved. For an effective patient presentation, it is important to understand that, in addition to a high-quality treatment plan and its presentation, a suitable environment is necessary in which the presentation can take place (see Fig 8). It is therefore critical to have a very sophisticated presentation room with all the technologies easily accessible to avoid losing momentum when telling the beautiful story of the patient's journey.

One of the key goals of the previous steps in the completely digital workflow is to create perceived value, which will eventually lead to case acceptance.

Steps 5 and 6: Guided Dentistry and Digital Quality Control

After case acceptance, two final concepts of Guided Dentistry and Digital Quality Control will help the team to deliver the treatment in the best possible manner using digital technologies to increase quality, efficiency, and predictability. These two concepts go hand in hand and are illustrated in Figures 10 to 12.

Digital dentistry is extremely helpful in overcoming one of the greatest limitations of restorative dentistry: the discrepancies between the initial plans and the final outcomes. In the past, the differences between an initial diagnostic wax-up and the final treatment result were usually tremendous. In addition, they unfortunately represented the rule and not the exception. Analog protocols have failed to address these limitations. It can be expected that, in the future, freehand intraoral procedures will no longer be performed, and all procedures will use some kind of digitally designed guide or device. This is the concept of Guided Dentistry. In addition, all procedures must be evaluated before moving on to the next step by comparing the initial simulation with the achieved result. By superimposing scans of the initial and the actual situation, discrepancies can be detected and corrective measures carried out, where necessary. This is the concept of Digital Quality Control.

Future outlook

A number of digital tools such as digital radiographs assist in the Digital Quality Control process. There are already programs available that apply AI and machine learning (ML) tools to read radiographs and detect certain pathologies and aberrations such as caries and marginal gaps. In the future, these tools will become automated and applied on a large scale to alert the clinician and the team to any quality related issues and concerns during follow-up visits, especially when they trigger adjustments or remakes. In fact, AI and ML will most likely be applied to automate almost all the steps of the complete digital workflow, from
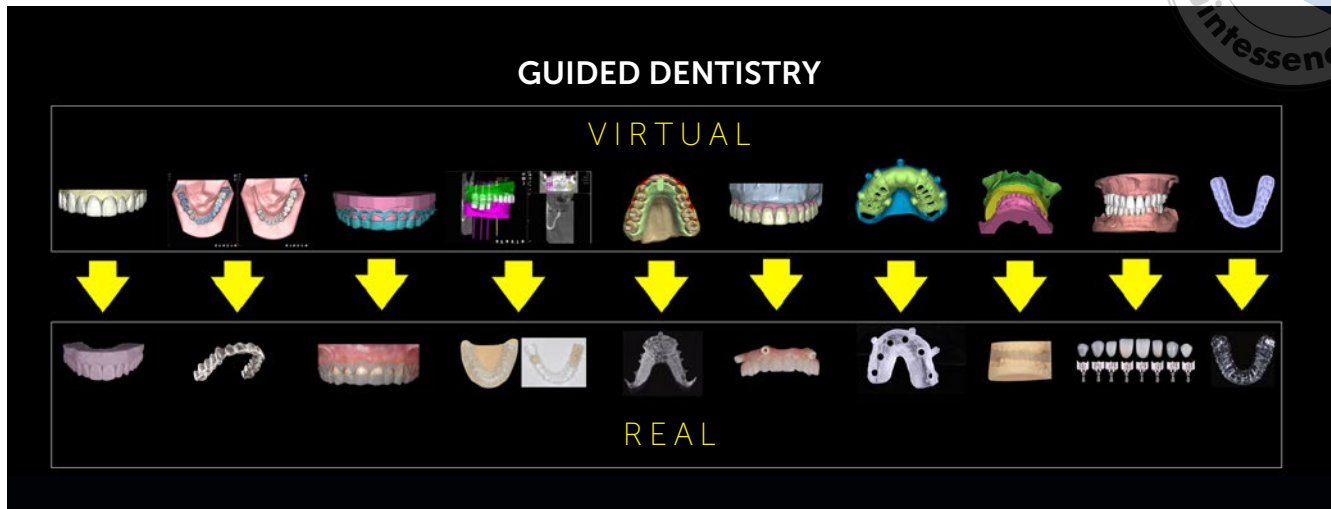
Fig 10 Guided dentistry overview. The treatment plan is developed based on the initial design (the final goal). All dental devices and guides are fabricated to minimize discrepancies between the plan and the final outcome.
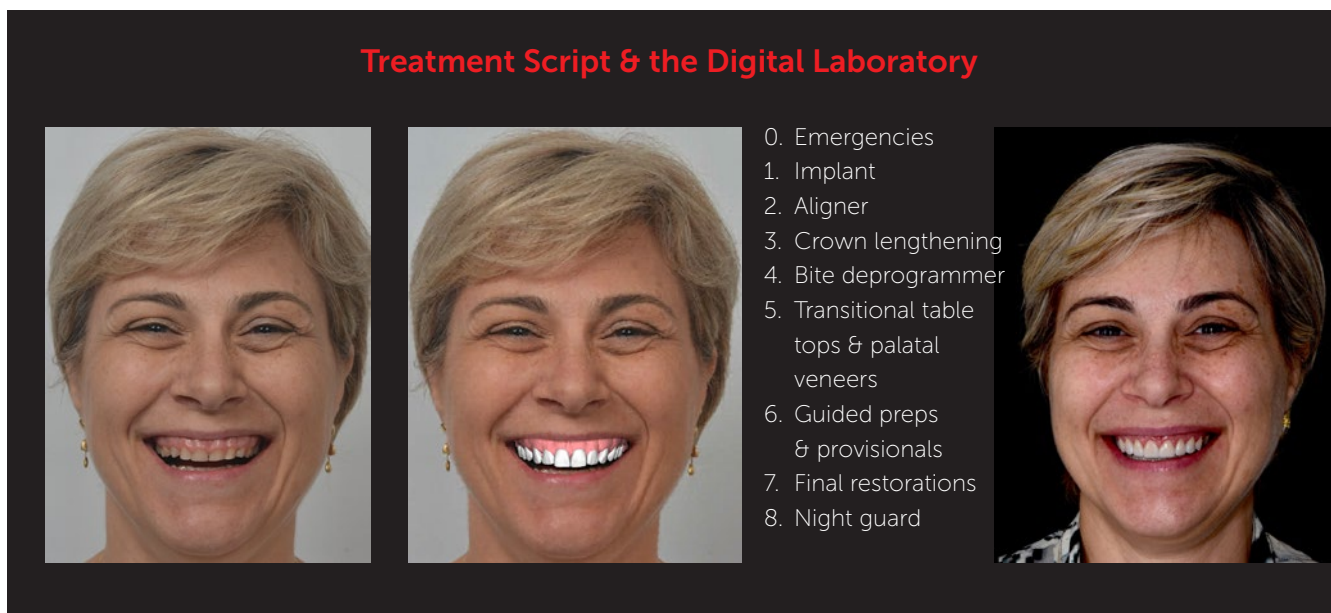

Fig 11 A facially driven smile design and treatment plan is translated into a 3D project. The project guides the development of a treatment 'script' that details the exact sequencing and timing of the procedures to be performed. Each procedure is guided by a dental device to preserve the precision of the initial ideal treatment plan as approved by the dentist and the patient.

Fig 12 Each procedure is guided by a dental device to preserve the precision of the initial ideal treatment plan as approved by the dentist and the patient. The situation is scanned after final healing and overlapped with the initial simulation for quality control analyses. (a) Preoperative situation. (b) Facially driven 3D smile design. (c) Transparency of the ideal design overlapped with the preoperative situation, visually showing the discrepancies that include the need for crown lengthening. (d) Design of a double crown-lengthening guide respecting the new ideal gingival margin and biologic width. (e) Guided soft tissue removal. (f) Guided bone removal. (g) The ideal design should be the reference for 3D quality control. (h) The scan after healing to overlap with the ideal design and for quality control of the surgical result as well as to show a possible need for refinement or approval of the outcome. (i) Intraoral situation after crown lengthening (j) Definitive ceramic restorations.

diagnostics and treatment planning to material selection and follow-up.[12] Critical errors that are based on human error or subjective opinions can consequently be minimized or even avoided. Current concepts related to 'intuitive ML' make these visions of automation even more likely.

Summary

The new complete digital workflow comprises six key steps, from digitalized patient information and cloud-based interdisciplinary treatment planning to digital simulation, case acceptance, guided treatment, and digital quality control. Based on the digitalized patient information, a facially driven smile design and treatment plan is translated into a 3D project. This project guides the creation of a treatment 'script' with the exact sequencing and timing of the procedures to be performed. Accordingly, guides and devices are fabricated to reduce the discrepancies between the plan, as approved by the dentist and the patient, and the ultimate outcome. The final outcome and the situation during follow-up visits are scanned and overlapped with the initial simulation for quality control purposes. Adjustments or retreatment can be carried out accordingly. Figure 7 summarizes key elements of the complete digital dental practice.

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