4 Current Digital Workflow for Implant Therapy: Advantages and Limitations

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4.1 Introduction

Digital technologies have been substantially incorporated into contemporary dentistry in the last decade to enhance the overall performance of dental treatment as it provides multiple advantages to aid in diagnosis, treatment planning, and procedure execution. The communication between clinicians, patients, and technicians has become more efficient with their introduction. The digital workflow is a sequential, predictable combination of data that permits the creation of three-dimensional (3D) structures and its final production with the desired material (Fig. 4.1). The initial stage is digital image acquisition, which can be from extra-oral, e.g., cone beam computed tomography (CBCT), a laboratory scanner, or intraoral means, e.g., an intraoral scanner (IOS). The introduction of IOS enables clinicians to obtain and store digital data of the surfaces of teeth and surrounding soft tissues in a reasonable time frame. Subsequent steps are usually referred as computer-aided design (CAD) and computer-aided manufacturing (CAM) (CAD-CAM) [1, 2]. This chapter is dedicated to discussing the concept of the digital workflow with emphasis on CBCT, IOS, and 3D-printing principles, accuracy, and their limitations.

4.2 CBCT in Implant Therapy

CBCT volumetric data provides three-dimensional (3D) radiographic imaging and became a valuable technology for the improvement of oral and maxillofacial diagnosis. Rapid technology development since the introduction of CBCT into the dental field resulted in the accessibility and spread of the 3D imaging to the

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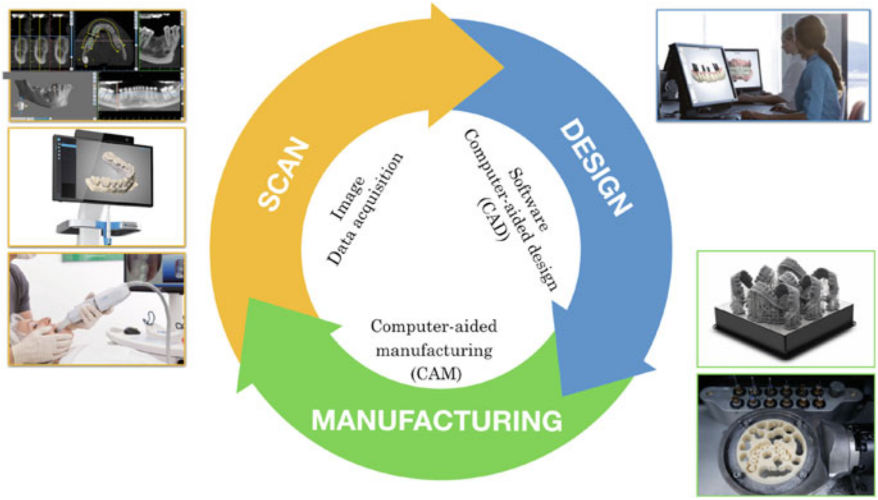

Fig. 4.1 The essential principle of digital workflow is based on three components: data acquisition, computer-aided design (CAD) software, and manufacturing of structures with the desired material through computer-aided manufacturing (CAM)

routine uses of dental practices. Currently, more than 85 different CBCT models are available with a variety of capabilities including multi-model systems with combined two dimensional (2D, panoramic and cephalometric) and 3D CBCT imaging, and less expensive panoramic units with limited 3D field of views. CBCT volumetric data is generated by a cone beam shaped X-ray that rotates with a reciprocating area detector around a fixed center which is the patient's region of interest (ROI). During the rotation, a series of sequential exposures are performed and multiple sequential planar projections are recorded into 2D individual planar images, constituting the raw primary data (basis, frame, or raw images). Software advanced algorithms transform the multiple raw data into a volumetric data set that can generate reconstructed images in the three orthogonal planes (axial, sagittal, and coronal). Generally, one rotational scan is sufficient to acquire enough data for volumetric reconstruction and the scan acquisition times are fast ranging from 5 to 30 s. Among many applications of CBCT imaging in oral and maxillofacial field, implant dentistry has been an area of great impact and the applications of CBCT has greatly expanded for not only the diagnostic, treatment planning, and post-surgical assessments but for advancement in areas where CBCT incorporates the digital workflow from the production of biomodels and surgical guides to surgical guidance assistance.

4.2.1 CBCT and Radiation Doses

Considerations in patient selection criteria and radiation effective doses are imperative for the correct prescription of CBCT imaging, given the higher radiation doses compared to other dental radiograph procedures. Based on the ALARA ("as low as reasonably achievable") principles, CBCT should be used as an adjunctive image modality when 2D radiographs are not sufficient to provide the information for the diagnosis and treatment of the patients and the potential benefits exceed and justify the individual detriment that radiation exposure may cause [3]. The American Academy of Oral and Maxillofacial Radiology (AAOMR), the American Dental Association ADA), and numerous consensus panels in implantology provide guidelines on the clinical applications, adequate prescription, radiation safety, and interpretation of CBCT imaging [4–6]. Given the great number and variety of commercially available CBCT units, a wide range of effective doses are present, based on the different FOV selections and CBCT units [7–10]. Approximately estimated values are provided in Table 4.1. Comparison with background radiation (approximately 8 μS/day) or with commonly used 2D radiographs: 4 posterior bitewings with effective doses of approximately 5 μS, Panoramic radiograph that ranges from 3 to 24 μS and a Full-Mouth series (~34 μS with rectangular collimator to ~170 μS with a round collimator) may be used as references to the different doses of CBCT units. Therefore, increased radiation doses in CBCT scan compared to some types of dental radiographs should be considered. However, the advantages of significantly lower radiation doses in CBCT imaging are greatly appreciated in comparison with a Multi-detector CT scan that has approximately 1000−2000 μS effective dose. It is important to understand that clinical parameters during image acquisition and machine parameters and protocol will affect both image quality and patient radiation dose. Optimal patient stabilization, use of coordinated pulsing X-ray generators and detectors, doses optimizations based on the patient size and diagnostic task, types of detectors, determination of the FOV or scan volume based on the patient's needs will reduce exposure, minimize scatter radiation, and increase the image quality.

Table 4.1 Effective dose range estimates in dental CBCT in adults and children at different field of views (FOV)

	Size of field of view (FOV)	Effective doses
Adult	Small FOV	5–652 μS
	Medium FOV	9–560 μS
	Large FOV	46–1073 μS
Child	Small FOV	7–521 μS
	Medium-large FOV	13–769

Adapted from Rios et al. [11]. μS—Microsievert

4.2.2 Advantages and Limitations of CBCT

Advanced technology in CBCT and software development not only improved the image quality with high-resolution scans but also optimized and facilitated the commercialization and availability of the CBCT units to the dental offices. In implant dentistry, it is well-established the benefits of multiplanar reformatting capacity in CBCT. Given the anatomic curvature present within the maxillary and mandibular arches, the basic orthogonal planes do not provide accurate visualization of the available buccolingual bone dimensions. Therefore, it is necessary that curved planar reformatting is performed based on the curvature of the maxillary or mandibular arches. Generation of specific multiplanar reconstructions in curved arches and cross-sectional views that are perpendicular to the potential implant site is imperative for accurate linear bone measurement of the available alveolar ridge height and width. Other advantages of CBCT are the high spatial resolution and relatively lower radiation doses when compared to Multi-Slice CT scans.

One of the biggest limitations of CBCT in imaging diagnosis is the poor soft tissue contrast that limits accurate visualization of soft tissue structures such as salivary glands, muscles, neurovascular structures, as well as soft tissue pathologies. Poor soft tissue contrast also hinders potential soft tissue integration in presurgical implant planning. Another limitation of the CBCT modality is limited bone density measurement as the lack of standardized measurements and inconsistent HU values are challenging. The presence of beam hardening and volume averaging artifacts around implants and metallic restorations have a significant impact on implant dentistry. These artifacts prevent and limit the visualization and accurate diagnosis of bone quality and quantity within the peri-implant areas. These limitations are significant for the post-surgical evaluation of areas surrounding implants: the evaluation of peri-implantitis and bone loss, the assessment of thin buccal or lingual bone quantity for possible dehiscence or fenestration of the implant. Moreover, the presence of artifacts degrades image quality that may affect the digital workflow and image fusion of CBCT with other digital modalities such as extra-oral facial or intraoral optical data. A summary of the advantages and limitations of CBCT is shown in Table 4.2.

4.2.3 Applications of CBCT for Diagnosis and Treatment Planning

Recommendations for the applications of radiography and CBCT imaging for dental implant patient are detailed below by the position statement of the American Academy of Oral and Maxillofacial Radiology, Table 4.3 [11]:

Basic principles in radiology should be applied in imaging for implant evaluations. The clinician should have appropriate training in operating the CBCT unit and have competency interpreting the 3D images. Knowledge of the normal anatomy of the oral and maxillofacial complex, the capability of identifying anatomic variations, abnormalities, and potential pathologies within the scan are

Table 4.2 Advantages and limitations of CBCT

Advantages	Limitations
Size and cost—the availability to dental offices	Poor soft tissue contrast
Multiplanar reconstruction	Image noise
Short time for data acquisition	Limited bone density measurement (HU)
High spatial resolution	Beam hardening artifacts created by metal
Relatively low radiation dose (compared with MDCT)	Increased radiation dose compared with 2D radiographs-dependent on CBCT unit and FOV selection
Virtual and interactive treatment planning	Technique sensitive to motion
Reliable linear and volumetric measurements	

responsibilities expected from the professional who ordered the scans [2]. The selection of appropriate FOV should be based on the patient's selection criteria. Nevertheless, it is important to consider that the bigger the FOV the more likelihood of having incidental findings due to more anatomical structures included within the volume. The practitioner is responsible for interpreting the entire volume captured and is liable for any missed diagnosis. Consultation with a qualified oral maxillofacial or medical radiologist should be considered if the practitioner is not familiar or is not willing to accept the responsibilities to review the entire CBCT volume.

CBCT data is exported in a medical diagnostic standard imaging format called Digital Imaging and Communications in Medicine (DICOM) file. DICOM files can be imported into third-party application-specific software, providing visualization and virtual simulations of the volumetric data for treatment planning and diagnosis. Several software programs are available for task-specific applications. The clinician should be comfortable in 3D diagnosis and become familiar with the available software applications for image interpretation and interactive treatment planning.

4.2.4 Anatomic Considerations in Implant Planning

CBCT imaging is a great diagnostic tool in implant planning to exclude the presence of incidental findings such as pathology, foreign bodies, and bone defects in the specific implant area or adjacent surrounding structures. For that, the clinician should be familiar with the normal oral and maxillofacial anatomy and be able to identify possible anatomy variants and predict future complications that may influence in the planning for the implant placement. Different minimal space requirements are necessary for safe implant placement, with at least 1.5 mm of a distance of the implant to an adjacent tooth, at least 3 mm of distance from the implant to an adjacent implant, and at least 2 mm of buffer space to vital anatomic structures such as the Inferior alveolar canal (Table 4.4).

Table 4.3 Recommendations for CBCT use in implant surgery per the position statement of the American Academy of Oral and Maxillofacial Radiology [12]

Recommendation 1	Panoramic radiography should be used as the imaging modality of choice in the initial evaluation of the dental implant patient
Recommendation 2	Use intraoral periapical radiography to supplement the preliminary information from panoramic radiography
Recommendation 3	Do not use cross-sectional imaging, including CBCT, as an initial diagnostic imaging examination
Recommendation 4	The radiographic examination of any potential implant site should include cross-sectional imaging orthogonal to the site of interest. This reaffirms the previously stated position of the AAOMR
Recommendation 5	CBCT should be considered as the imaging modality of choice for preoperative cross-sectional imaging of potential implant sites
Recommendation 6	CBCT should be considered when clinical conditions indicate a need for augmentation procedures or site development before placement of dental implants: (1) sinus augmentation, (2) block or particulate bone grafting, (3) ramus or symphysis grafting, (4) assessment of impacted teeth in the field of interest, and (5) evaluation of prior traumatic injury
Recommendation 7	CBCT imaging should be considered if bone reconstruction and augmentation procedures (e.g., ridge preservation or bone grafting) have been performed to treat bone volume deficiencies before implant placement
Recommendation 8	In the absence of clinical signs or symptoms, use intraoral periapical radiography for the postoperative assessment of implants. Panoramic radiographs may be indicated for more extensive implant therapy cases
Recommendation 9	Use cross-sectional imaging (particularly CBCT) immediately postoperatively only if the patient presents with implant mobility or altered sensation, especially if the fixture is in the posterior mandible
Recommendation 10	Do not use CBCT imaging for periodic review of clinically asymptomatic implants. Finally, implant failure, owing to either biological or mechanical causes, requires a complete assessment to characterize the existing defect, plan for surgical removal and corrective procedures, such as ridge preservation or bone augmentation, and identify the effect of surgery or the defect on adjacent structures
Recommendation 11	Cross-sectional imaging, optimally CBCT, should be considered if implant retrieval is anticipated

4.2.4.1 Anterior Maxilla

A common limitation in the anterior maxilla is buccal bone atrophy and associated prominent buccal concavity resulting in a limited residual ridge. Anatomic structures that should be evaluated within the anterior maxilla are the floor of the nasal cavity, evaluation of the morphology, and size of the nasopalatine canals and incisal foramen that may limit the available bone width depending on the size, location, and the overall trajectory of the canals [9].

Table 4.4 Minimal distances from implant to adjacent structures and anatomic considerations for implant planning

Anatomical structure	Consideration
Implant distance to adjacent teeth	At least 1.5 mm
Implant distance adjacent implant	At least 3 mm
Implant distance to vital anatomic structures	At least 2 mm
Anterior maxilla	Floor of the nasal cavity
	Prominent buccal concavity and limited residual ridge
	Variable width of nasopalatine canals
Posterior maxilla	Sinus pneumatization
	Antral septa
	Sinus disease
	Prominent posterior superior alveolar artery
Anterior mandible	Prominent buccal concavity and limited residual ridge
	Anterior loop and mandibular incisive canal
	Mental foramen
	Lingual canal
Posterior mandible	Mental foramen
	Inferior alveolar canal
	Lingual inclined alveolar ridge and lingual undercut

4.2.4.2 Posterior Maxilla

The sinus floor position and morphology are important anatomic structures within the posterior maxilla. The sinus floor is a limiting factor for the available bone height, especially in cases of severe pneumatization and the presence of antral septum that may result in the variability of height measurements (Fig. 4.2). It is important to identify any potential inflammatory sinus disease such as sinusitis, or prominent neurovascular canals when sinus lift procedure is planned (Fig. 4.3). Recommendation for further evaluation by an otorhinolaryngologist is suggested in case the pathology of sinuses is identified prior to implant-related surgical procedures [13].

4.2.4.3 Anterior Mandible

Buccal concavity and limited residual ridges are also limitations for available bone height and width in the anterior mandible. The identification of prominent neurovascular structures within the anterior mandible that includes the presence of mandibular incisive foramen, prominent lingual canal, mental foramen position, and the possibility of the anterior loop is valuable to predict possible neurovascular damage and exacerbated bleeding [14] (Fig. 4.4).

4.2.4.4 Posterior Mandible

The inferior alveolar canal may be the reference for available bone height measurements in the posterior mandible. Visualization of the inferior alveolar canal cortices

Fig. 4.2 Sinus perforation. CBCT imaging: Panoramic reconstruction (top) and cross-sectional reconstructions (bottom) of the right maxillary sinus show sinus perforation by implant at the edentulous site #4. Associated mucosal thickening is noted along with the implant and the sinus floor

may not be very clear in some patients and caution should be considered to avoid nerve damage. The mental foramen is usually positioned within the premolars sites and limits the available height and width depending on the foramen morphology. The posterior mandible also may present anatomical limitations when the alveolar crest has lingual inclination or in cases where there is a prominent submandibular gland depression resulting in a prominent lingual undercut. These may limit the available bone height and width and affect the position of the potential implant towards the lingual plate. Caution to not perforate the lingual cortex in the areas of lingual undercut should be considered [15–17] (Fig. 4.5).

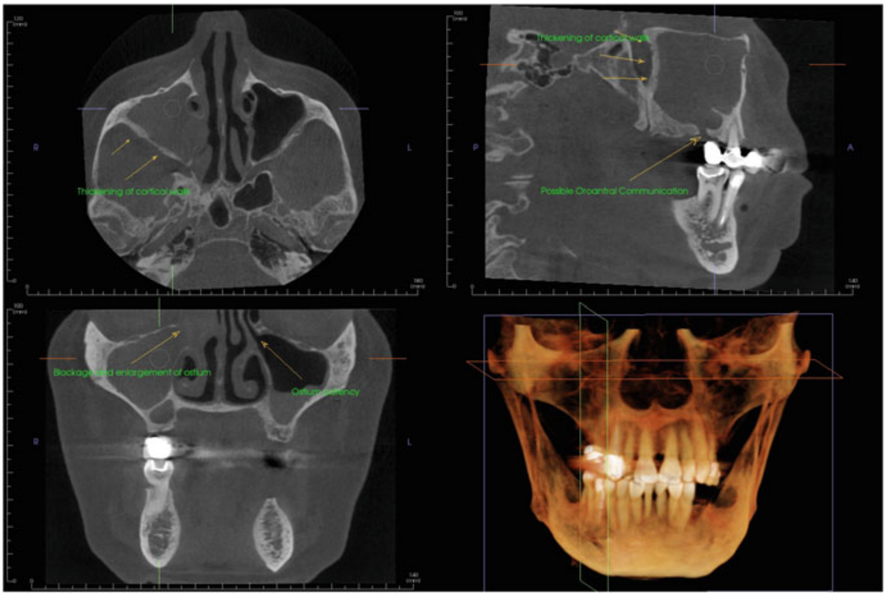

Fig. 4.3 Maxillary sinus disease. CBCT image in axial (top left), sagittal (top right), coronal (bottom left), and volume rendering reconstruction (bottom right). The right maxillary sinus is completely filled and the ostiomeatal complex is obstructed (coronal view). There is a surgical defect with likely oroantral communication in the edentulous site of #4. The right maxillary sinus also has soft tissue density along the floor, but the ostiomeatal complex is patent

4.2.5 Assessment of Bone Quality

Quality of bone is crucial for successful implant treatment providing ideally primary stability and conducive osseointegration. Because of a lack of reliable and consistent bone density measuring capabilities in CBCT owing the geometric beam shape, increased scatter radiation, lower contrast resolution, and lack of standardization among CBCT units [18, 19], radiographic validation of the bone quality for implant planning is based on subjective radiological observations of the cortical thickness and trabeculation density and appearance. Significant research advancement warrants promise in the areas for the quantitative CBCT method that would allow structural and quantitative bone analysis [20, 21]. Beneficial outcomes of bone assessment include presurgical assessment of bone quality, especially considering vascularization potential for conducive osseointegration [22]. Additional research is needed for further technology development in this area.

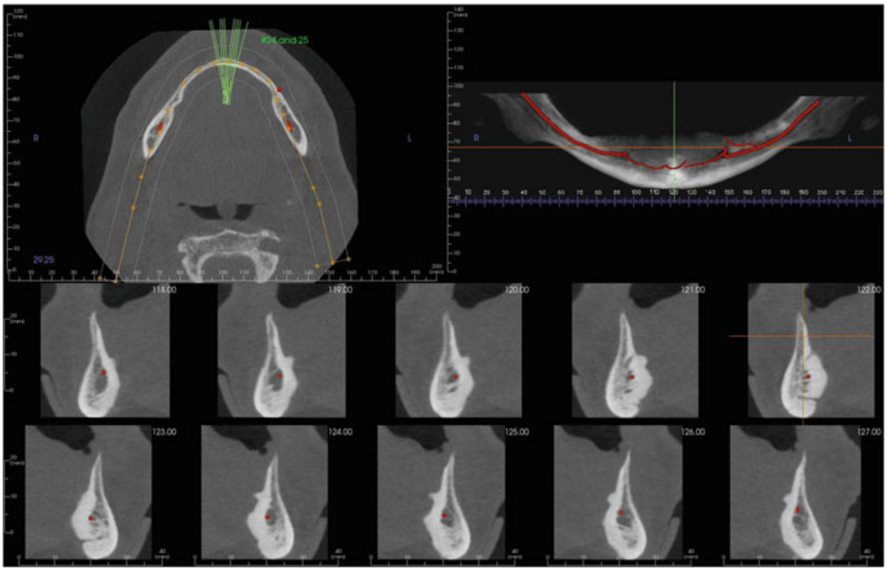

Fig. 4.4 Anterior mandibular anatomic challenges. CBCT image in axial (top left), reconstructed panoramic (top right) with tracing of Inferior alveolar canal (red lines) and multiple cross-sections (bottom). There is significant buccolingual bone atrophy with limited alveolar bone width. IAC tracing was performed showing anterior loop and extension of the mandibular incisive canal and lingual canal

4.2.6 Computer-Guided Implant Planning

CBCT permits reliable and consistent evaluation of the bone to determine suitability for implant placement, thickness of the cortical plate, quality of the bone trabeculation, anatomical characterization of the bone morphology as well as the relationship with the surrounding anatomical structures. Technology advances in CBCT resulted in a shift of treatment planning from a surgical driven approach based on the availability of bone that would dictate the implant positioning to a prosthetically driven approach, where final results based on functionality and aesthetics are great considerations for surgical decision and implant positioning [23].

There are numerous specialized software available for implant treatment planning. The software will provide an implant library with a variety of commercially available implants, with different sizes and dimensions, as well as customized corresponding overlays for ideal virtual implant placement and prosthetic rehabilitation. Optimal virtual implant planning is achieved by implant parallelism, considering individual anatomy, prosthetic functionality, and aesthetics. Therefore, CBCT volumetric imaging provides information on bone availability and anatomy, angulation of the implant relative to adjacent teeth, and available distance to key structures. Moreover, virtual implant planning assesses the needs for bone augmentation and the suitable timing of the augmentation if it can be accomplished

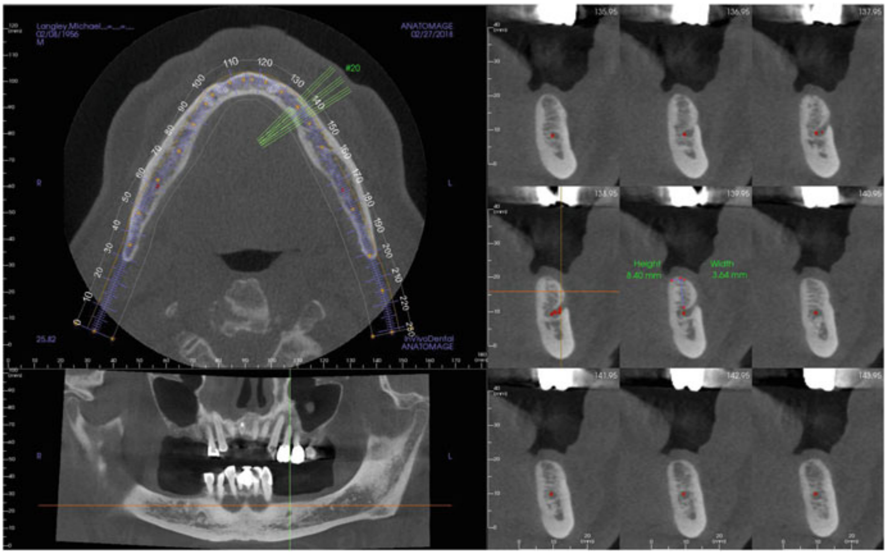

Fig. 4.5 Posterior mandibular anatomic challenges. CBCT image in axial (top left), slice panoramic view (bottom left) and cross-sections (right). Cross-sections shows limited bone height in the edentulous area of #20, where mental foramen is positioned

during implant placement or prior to. Possibility of combining the virtual planning with other technology with CAD/CAM -design surgical guide fabrication, intraoral scans, and computer-guided dental implant placement is a great quality of multiple 3D assets. The limitations with virtual implant planning are the need for transferring of data from presurgical planning to surgery. This is a multistep approach, which requires CBCT data acquisition, image interpretation, volume segmentation for preparation of models, surgical guides, registration of 3D impression scan on top of the 3D model so that it can lastly be transferred into a surgical setting. Therefore, minimizing errors in each step to avoid discrepancies from the virtual planning to the implant surgery is crucial for a successful virtual treatment planning and execution [24]. Optimization of the CBCT scan acquisition for better resolution and image quality will be key for a successful surgery outcome [25]. Box 1 lists CBCT image acquisition considerations for image optimization.

Box 1 Clinical suggestions for optimal CBCT acquisition when virtual planning is indicated

- Select the smallest FOV possible to avoid the inclusion of unnecessary areas that may contain metallic restorations.
- Minimize the presence of artifacts.

(continued)

- Minimize patient movement.
- Selection of optimal scanning resolution to control the noise and artifacts
- Confirm perfect occlusal/ridge fit when images are acquired with radiographic scanning templates.
- Separation of upper and lower jaws is recommended when bone segmentation is necessary
- Utilize cotton rolls to separate the cheek and lips when visualization of the gingiva outline at the facial site is necessary.

4.2.7 CBCT and Post-Surgical Evaluation

Two-dimensional periapical radiographs are still the recommended image modality for post-surgical evaluation of implant placement assessment and osseointegration evaluation. Bitewings may be used during the prosthetic phase when implant abutment and restoration fit confirmation are necessary, as well as adequate bone level evaluation. CBCT images application for post-surgical evaluation are indicated for the assessment of bone graft healing and morphology, or when clinical complications are suspected, such as neurovascular damage, incorrect implant placement or intrusion into the sinus, or obvious perforation of bone plates. CBCT also may be a useful resource for evaluation of alveolar dimension changes during the post-surgery healing time. CBCT limitations from metal-derived artifacts such as beam hardening and volume averaging result in darkening, overestimation of implant width, and equivocal bone-implant interface. Therefore, CBCT imaging may not be reliable when bone loss and peri-implantitis are considered. A similar problem occurs when thin bone cortication is present surrounding the implant or dehiscence is considered. Visualization and accuracy of bone content are challenging in areas surrounding implant and metallic restorations. Ongoing research is being done to reduce or overcome metal-derived artifacts in CBCT imaging [23, 26–28]. Metal artifact reduction (MAR) correction algorithms are being implemented in commercially available machines and have potential improvement of image quality with artifact reduction. However, more research is warranted for the evaluation of the effectiveness of technology development and implementation in this area, especially considering the great variability and inconsistencies of parameters among the different CBCT units.

4.3 Digital Workflow for Implant Therapy

The implementation of digital technologies in implant dentistry goes beyond the fascinating computerized world and should be focused in what the technology can offer by simplifying the workflow and improving patient satisfaction. Therefore, the digital workflow can be adapted to user preference and logistics, and different levels

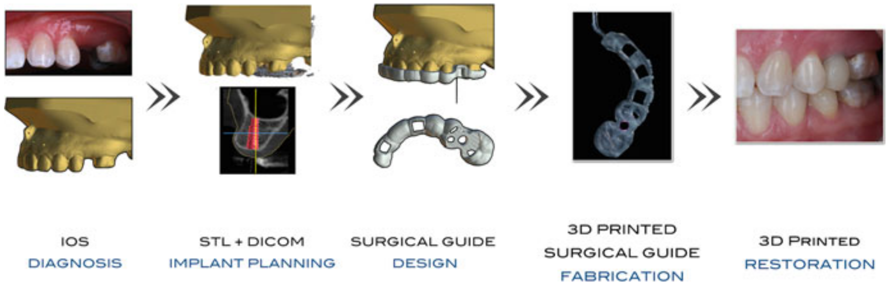

Fig. 4.6 An example of the complete digital workflow: from the treatment planning phase to surgical phase and prosthetic rehabilitation

of implementation can be achieved with the interchangeable combinations with analogue steps. The digital workflow for implant surgery can be either fully digital (direct acquisition of the virtual image from the oral cavity with an IOS device) or partially-digital (digitalization of a dental stone cast with an IOS or extra-oral scanner device, commonly referred as a bench or laboratory scanner). The acquired imaging data is then outputted in .STL (an abbreviation of "stereolithography" or backronyms such as "Standard Triangle Language" and "Standard Tessellation Language") file (Fig. 4.6). The .STL file is combined with the .DICOM (Digital Imaging and Communications in Medicine data) CBCT file in a treatment planning software for a computer-guided surgery (CGS). With the software, the implants can be virtually placed and surgical guides can be designed and exported in .STL files that will be utilized for milling or 3D printing fabrication. Further details regarding techniques and materials for implant surgery will be discussed in this chapter.

4.3.1 Intraoral Digital Acquisition

Intraoral scanners (IOS) are devices for capturing non-contact digital impressions through projection of a light source (laser, or more recently, structured light) onto the object to be scanned, in this case the intraoral structures. Dental and gingival tissue surfaces captured by the imaging sensors are processed by the scanning software, which generates point clouds that will be then triangulated by the same software, creating a three-dimensional (3D) surface model (mesh). Intraoral digital scanners allow clinicians to record the surface of the teeth, implant scan bodies, and surrounding soft tissues in 3D. The images enable clinicians with instant visualization and evaluation of the structure of interest, and seamless communication with the laboratory personnel. They can also be exported to a 3D-printer, or a chairside milling unit for prosthesis manufacturing [29–31]. Intraoral digital impression has progressed beyond single tooth preparations and quadrants scanning to full-arch scanning with more user-friendly features in the past few years (Fig. 4.7).

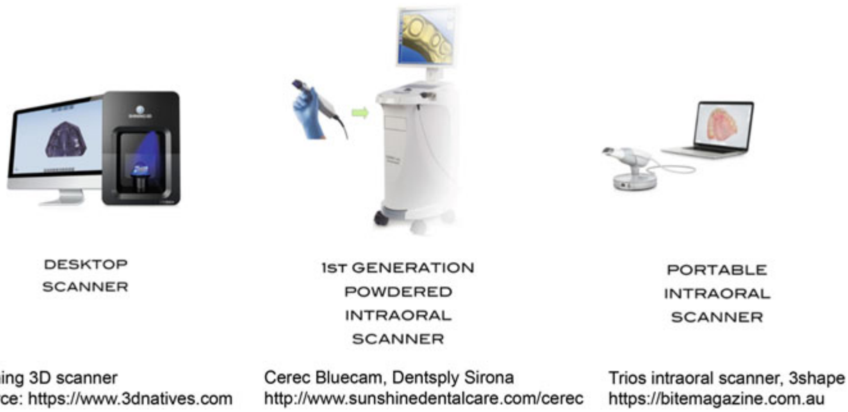

Fig. 4.7 The different generations of scanners utilized in dentistry. The powder-free intraoral scanners gained in popularity in the last decade and the most recent models are more accurate, smaller and faster

Several studies have compared digital impressions to conventional methods; most recent published data suggest optical impression has higher accuracy, improved patient satisfaction, working time reduction, dentists' preference and provides a platform for interdisciplinary communication [19, 32, 33]. There are many devices currently commercially available with different features, e.g., powder use, scanning speed, tip size, and ability to detect in-color impressions [29]. The first generation of scanning systems frequently needs powder use, is monochromatic and is a closed system, i.e., only proprietary files as output or semi-closed (pay per .STL file) [31, 34]. The latest devices are generally powder-free, faster and allow in-color impressions. They are mostly open systems (free. STL and .PLY [Polygon File Format or the Stanford Triangle Format] files). The currently available IOS is constructed on one of the three main principles: confocal laser scanner, active wave front sampling, and optical triangulation technique. Table 4.5 provides a summary of commonly used commercially available intraoral scanners.

4.3.2 Digital Versus Conventional Impressions

The ultimate goal of a dental impression is to accurately reproduce teeth surface and surrounding soft tissue contours. Conventional impression techniques are still considered the gold standard [35] and the most widely used. However, the use of digital impressions has been increasing significantly. Recently, many laboratory and clinical studies comparing both approaches have been conducted and are summarized below.

Table 4.5 Comparisons of the features of commonly used intraoral scanners

Digital intraoral scanning systems						
Intraoral scanner	Company	Working principle	Light source	Powder free	Output format	Website
Midmark Mobile True Definition[a]	Midmark	Active wave front sampling	Pulsating blue light	No	Proprietary or STL	Midmark.com/truedef
TRIOS	3Shape A/S	Confocal laser scanner	Blue LED light	Yes	Proprietary or STL	3shape.com
iTero Element	Align Technology	Confocal laser scanner	Red Laser	Yes	Proprietary and STL	Itero.com
Carestream Dental 3700	Carestream Dental	Optical triangulation	Light	Yes	Proprietary and STL	Carestreamdental.com
CEREC Bluecam	Dentsply Sirona	Optical triangulation	White light	No	Proprietary	Dentsplysirona.com
CEREC Omnicam	Dentsply Sirona	Optical triangulation	White light	Yes	Proprietary and STL	Dentsplysirona.com
Primescan	Dentsply Sirona	Optical triangulation	Blue light	Yes	Proprietary and STL	Dentsplysirona.com
Virtuo Vivo	Dental Wings	Blue Laser-Multiscan Imaging™ technology	Blue laser	Yes	Proprietary and STL	Dentalwings.com
Medit I500	Medit	Optical triangulation	Blue laser	Yes	STL, OBJ or PLY	Medit.com

[a]Previous 3M

4.3.2.1 Laboratory Studies

Milled models fabricated from digital impression images were comparable to gypsum models obtained from conventional impression [36]. Dies generated from IOS did not present clinical difference compared to those generated from conventional polyvinyl siloxane (PVS) [37]. Two IOS systems (Omnicam and True Definition) were tested and found their accuracy being clinically acceptable [39]. One study simulating full edentulous ridge impression found no difference between digital and conventional impressions, and an implant angulation of up to 15° did not affect the accuracy [40]. Limitations of complete arch scanning, e.g., mobile tissues, a lack of landmarks, and a long-distance between implants reduce the accuracy [8,26]. Artificial landmarks [41] and an auxiliary geometric device (AGD) [42] were recently used to improve accuracy. However, a recent systematic review reported that the available data on the accuracy of digital impressions have a low evidence level and do not include sufficient data on in-vivo application to derive further clinical recommendations [25].

4.3.2.2 Clinical Studies

Single implant impression with IOS is in general more accurate than a long span partial edentulous ridge or complete edentulous ridge impression. One study showed only 1 of the 21 scans demonstrated an acceptable interimplant distance (<100 μm) and an acceptable angulation error (<0.4°) [8]. Another study using IOS found angulation errors ranging from 5.0° to 8.5°, interimplant distance errors ranging from 160 to 270 μm, and linear displacement errors ranging from 270 to 450 μm in edentulous patients [6]. These results indicated that it is possible to perform a digital impression of multiple implants, however, further clinical investigations are still needed to approve the predictability of the results [43, 44].

4.3.2.3 Accuracy Comparison Between Different Intraoral Scanners

Accuracy refers to the trueness and precision. Trueness describes the closeness of a measurement to the actual value, and precision describes the closeness of multiple measurements (see Fig. 4.8) [23, 33].

Five systems were compared with the True Definition (3M ESPE Dental Products, Seefeld, Germany) showing the highest overall "trueness," followed by CS 3500 intraoral scanner (Dental Imaging software 6.14.0; Carestream Health Inc., Brunn am Gebirge, Austria). Zfx IntraScan (software version 5.02; Zfx GmbH, Dachau, Germany), CEREC AC Bluecam (software version 4.2.4.72893; Sirona, Bensheim, Germany), and CEREC AC Omnicam (software version 4.2.3.68181; Sirona, Bensheim, Germany) showed higher differences from the reference data set than the control group. Nevertheless, all tested IOS technologies seemed to be able to reproduce a single quadrant within clinical acceptable accuracy [45].

A similar comparison of 7 systems was performed [33]. PlanScan (Planmeca Group, Helsinki, Finland) had the best trueness and precision, while the 3Shape Trios was the poorest for sextant scanning. For complete-arch scanning, the Carestream 3500 (CS) (Carestream Dental) had the best performance, while the powdered scanning system CEREC Bluecam (CB) (Dentsply Sirona) showed the

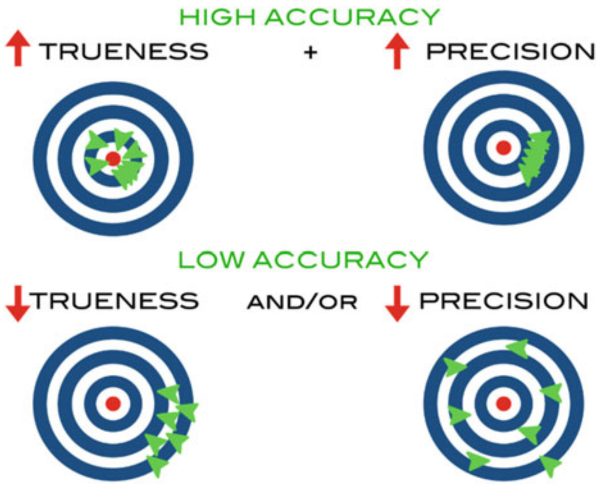

Fig. 4.8 Accuracy, combination of trueness and precision; illustratively described

least precision. 3Shape TRIOS 3 provided the best combination of speed, trueness, and precision.

Eight different IOS systems were compared and concluded that 2 systems (Dental Wings and 3D Progress) demonstrated a low performance showing average deviations between 148 and 344 µm, while 2 systems (True Definition and Trios 3) presented the best performance with only 31 and 32 µm of average deviation, which is clinically insignificant [21].

It is known that scanners differ regarding the speed, trueness, and precision of sextant or complete-arch scans and the results of studies comparing different scanning systems should be interpreted with caution, since they were performed without a standardized method to evaluate and compare multiple IOS systems.

4.3.2.4 Time-Efficiency of Intraoral Scanners

There is a learning curve with the use of new devices and techniques, as reported in a clinical study that the average scanning time decreased from 16.7 min for each of the first 40 patients to 9.5 min for each of the last 20 cases [46]. Garino et al. used the iTero powderless scanner and after 328 scans, the mean scanning time was 11 min and 58 s [47]. Yuzbasioglu et al. tested the CEREC Omnicam in a sample of 24 adults and found that the mean scanning time was significantly lower than the time required for conventional impression with a polyether material [48]. Similar findings were reported from other groups that there was a significantly reduced chair time for the digital workflow for implant crowns (14.8 min) compared to the conventional approach (17.9 min) [32]. A recent clinical trial also reported a significantly reduced time for digital impression technique (10.9 min) compared to the conventional method (14.3 min) [49]. Table 4.6 provides a summary of working time for IOS compared to conventional impressions reported in clinical studies.

Table 4.6 Time operating of intraoral scanning reported in clinical trials

Study/design	Patients/implants	Prosthesis	Intraoral scanner	Area of scanning	Conventional impression material	Digital impression time started	Impression technique	Number of procedures evaluated	Procedure time (min) Mean ± SD[a]
Joda and Bragger [32] RCT[b]	20/40	Single implant-supported crowns	iTero; Align Tech	Quadrant scan	Polyether (Impregum Penta; 3M)	Removal of cover screwed and insertion of scan body	Digital	20	14.8 ± 2.2
						Removal of cover screwed and insertion of transfer post	Conventional	20	17.9 ± 1.1
Schepke et al. [50] Prospective	50/50	Single implant-supported crowns	Omnicam; Dentsply Sirona	Complete-arch	Polyether (Impregum Penta; 3M)	Removal of intraoral scanner from scan unit	Digital	50	6.39 ± 1.85
						Removal Beginning of mixing procedure	Conventional	20	12.13 ± 1.4
Wismeijer et al. [51] Prospective	27/38	Single and partial fixed implant-supported prosthesis	iTero; Align Tech	Quadrant scan	Polyether (Impregum Penta; 3M)	Removal of cover screwed and insertion of scan body	Digital	27	23.44 ± 9.08
						Removal of cover screwed and fabrication of individual tray	Conventional	27	15.18 ± 5.46
Pan et al. [49] Prospective	20/40	Single implant-supported crowns	3Shape Trios Standard ® 11, 3Shape A/S	Complete-arch	Polyether (Impregum Penta; 3M)	Tray selection to color determination	Digital	20	10.9 ± 2.1
						Removal of healing abutment to color determination	Conventional	20	14.3 ± 3.0

[a]SD, standard deviation
[b]RCT, randomized clinical trial

4.3.2.5 Patient Reported Outcomes

There was an overall patient preference for the digital impression, compared to the conventional method, even though the patients had perceived the duration of IO scan more negatively than conventional approach [51]. More recent studies showed the benefits of IOS, even for patients who had no experience with either conventional or digital impressions previously. [32, 48].

The overall patient experience evaluated with the visual analogue scale (VAS) questionnaires favored the digital technique. All patients would select the digital workflow if they need future implant prosthetic treatments [52]. A recent study reported the comfort, anxiety, and taste were significantly better with the IOS [19]. Table 4.7 is a summary of recent clinical trials reporting patient experience to digital impression compared to conventional technique for implant-supported restorations.

4.3.2.6 Operator Experience

A pilot study revealed that the digital technique was preferred by 60% of the second-year dental students, while 7% preferred conventional impressions and 33% were satisfied with either technique [54]. Overall, the participants' perceptions of difficulty and applicability tended to favor digital impressions. Students expressed an expectation that digital technologies being a time-saving procedure [4] will become the predominant impression technique in their future careers [55]. On the other hand, experienced dentists favored the conventional method, indicating that this group was reluctant to adopt this new technology [56]. Repeated experience can affect the trueness of the scanned images [57, 58].

4.3.2.7 Limitations of Intraoral Scanning

As good as it is, IOS only capture the surfaces of the oral structures. There is no depth information and the dynamic function of soft tissues cannot be evaluated. The presence of saliva, patient movement during scanning, mobile mucosa, highly reflecting surfaces, or access difficulties are the major limitations [59, 60]. Patient and saliva control rely on operator execution and teamwork. Geometric devices have been utilized to overcome areas with mobile mucosa and long distance between teeth and/or implant scan bodies. The initial cost seems to be an important challenge for the introduction of the digital workflow. At the same time, a recent published article showed that digital impressions are more efficient and cost effective than standard impressions, and implementation costs can be offset within the first year [61].

4.4 Computer-Aided Design (CAD)

Computer-aided design comprises of software which allows the integration of the digital data and provides tools for dental appliance manufacturing. A transition from closed to open-source CAD/CAM technologies has created greater flexibility in the digital workflow. Various data acquisition sources, e.g., IOS, laboratory cast scanner, and CBCT, can be combined with different compatible software programs

Table 4.7 Patients preferences evaluated in clinical trials when digital impression is compared to conventional impressions for implant-supported rehabilitations

Study design	Patients implants	Prosthesis	Intraoral scanner	Area of scanning	Evaluation method outcome reported	Result
Wismeijer et al. [51] Clinical observa-tional	27/38	Single and partial fixed implant-supported prosthesis	(iTero; Align Tech)	Quadrant scan	Self-developed questionnaire/treatment time taste nausea sensation comfort	Digital impression overall experience significantly more favorable than conventional impression technique ($P = 0.026$). Negative correlations found between patient satisfaction and time involved for digital impression technique
Schepke et al. [50] prospective	50/50	Single implant-supported crowns	(Omnicam; Dentsply Sirona)	Complete-arch	VAS/comfort and anxiety	During conventional impression technique participants experienced more discomfort, more feelings of helplessness, and more shortness of breath than during digital impression ($P < 0.001$)
Joda and Bragger [32] RCT	20/40	Single implant-supported crowns	(iTero; Align Tech)	Quadrant scan	VAS/convenience, anxiety taste, nausea sensation and pain	Overall patient preference for digital impression higher than conventional impression technique ($P < 0.001$)
Delize et al. [19] Clinical, non-randomized	31/31	Single implant-supported crowns	IOS (TRIOS® second generation, 3Shape)—newly experienced operators	Quadrant scan	VAS/pain, comfort, nausea, taste, anxiety	No difference was found for pain ($p = 0.99$) and treatment duration ($p = 0.71$). However, the comfort ($p = 0.0087$), anxiety ($p = 0.031$), and taste ($p = 0.014$) domain results were significantly better with the IOS. A trend was observed for nausea ($p = 0.074$)
Guo et al. [53] prospective	20/20	Single implant-supported crowns	(Trios 1, 3Shape Trios Standard-P11, 3Shape A/S, Copenhagen, Denmark)	Complete-arch + refined area after implant placement	VAS/overall convenience, anxiety, taste, nausea, difficulty breathing and the possible sensation of pain	Among the 20 patients, 17 showed a preference for the immediate digital impression technique (85%), and three expressed indifference regarding the impression methods

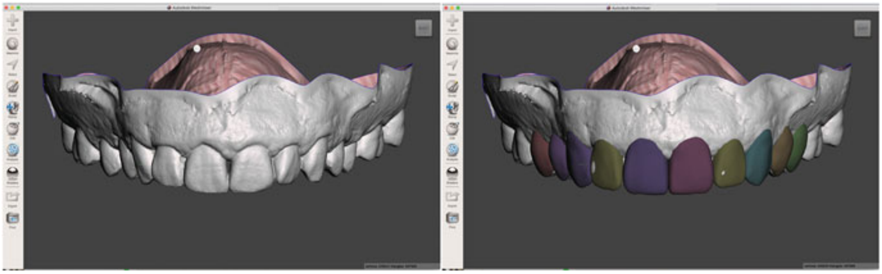

Fig. 4.9 Wax-up designed in a free 3D sculpting-based CAD software (Computer-Assisted Design), Meshmixer—Autodesk

[43]. A trend in today's digital dentistry is the push for "open systems" and the CAD software does not necessarily need to be dental specific. As an example, Meshmixer is a powerful 3-D design software that can be used to create 3-D models, wax-ups, occlusal splints, or even dentures (Fig. 4.9). Use of open-source software may reduce the cost and gain more acceptance.

Certainly, the learning curve for the use of an open-source system, especially those not dental specific, is more difficult. Table 4.8 presents examples of CAD software and their principal features. Intriguingly, a recent study confirmed that as the number of repetitions increased to digitally design the abutment, the skill increased and the time spent to complete the task decreased [62].

4.5 Computer-Aided Manufacturing (CAM)

Computer-aided manufacturing (CAM) refers to the final step on the "digital workflow" when the data created using CAD is used for manufacturing of structures with the desired material. There are two methods of CAM currently available: addictive manufacturing (AM) and subtractive manufacturing (SM). Subtractive manufacturing is a process that removes or grinds a specific material to form the final object. This technology has dominated the fabrication of dental prosthesis and other dental devices in the past three decades; however, it involves higher costs and a significant waste of material. AM or 3D printing is based on the addition of consecutive two-dimensional (2D) layers of material to form the customized 3D object of interest. Being at a lower cost, 3D printing has become the preferred method to produce models, surgical templates, and interim prosthesis fabrication.

4.5.1 Additive Manufacturing: 3D Printing

Additive manufacturing and 3D printing are becoming increasingly important in many surgical fields, e.g., neurosurgery, heart surgery, craniomaxillofacial surgery, and implant dentistry [63]. There are numerous advantages in the area of computer-

Table 4.8 Examples of CAD software and their major characteristics

Digital intraoral scanning systems				
CAD software frequently used in dentistry				
Software name	Company	Major indication	User friendliness	Cost
Simplant	Dentsply Sirona	Implant planning software	Company executes planning and clinician reviews it	$$[a]
NobelClinician	Nobel Biocare	Implant planning software	Easy to use	$$
coDiagnostiX	Dental Wings	Implant planning software	Easy to use	$$[a]
Blue Sky Plan	Blue Sky Bio	Implant planning and orthodontics software	Easy to use	$[b]
Implant Studio	3shape	Implant planning software	Easy to use	$$[a]
Exoplan	Exocad	Implant planning software	Easy to use	$$
Galileos Implant	Dentsply Sirona	Implant planning software	Easy to use	$$
Meshmixer	Autodesk, Inc	3D CAD software	Not user friendly for dental	$
Geomagic Freeforms	3dsystems	Engineering software	Not user friendly for dental	$$
Blender Dental	Blender foundation	3D CAD software with dental module	Relatively user friendly with dental add-on	$$

[a] $$—license required for software usage or free software + fee for guide fabrication from company
[b] $—free software (might need to pay to export data)

assisted surgery, such as treatment time reduction, high accuracy, and overall cost reduction. Today a large number of 3D printers with different printing technologies along with resin materials are available. The most utilized 3D-printers in implant dentistry will be briefly described in this chapter.

4.5.1.1 Fused Deposition Modelling (FDM)

In the fused deposition modelling (FDM) machines, filaments of a thermoplastic material, e.g., polylactic acid (PLA) polymers, are heated and then extruded through the nozzle to build precise structures. Favorable properties, e.g., strong and stiff, make PLA polymers suitable for use in the oral cavity. Some studies have added biological compounds into the build filaments. Thermoplastics-infused biodegradable polyester with bioactive tri-calcium phosphate has been shown to be a promising prospect for use in building tissue scaffold structures in dentistry [10].

4.5.1.2 Stereolithography (SLA)

SLA printers create structures layer by layer using ultraviolet light or laser to solidify a liquid photopolymerizing resin. These polymers (resin) offer a flexibility in color, rigidity, and modification of components. Light-cured resins may be used for a variety of purposes such as: dental casts, wax-ups, surgical template guides, temporary crowns, dentures, etc.

4.5.1.3 Selective Laser Sintering (SLS)

SLS constructs scaffolds from 3D digital data by sequentially fusing regions in a powder bed, layer by layer, via a computer-controlled scanning laser beam. Layer-by-layer additive fabrication in SLS allows construction of scaffolds with complex internal and external geometries. Any powdered biomaterial that will fuse but not decompose under a laser beam can be used to fabricate scaffolds. Additionally, SLS does not require the use of organic solvents, can be used to make intricate biphasic scaffold geometries, and does not require the use of a filament (as in FDM). It may be easier to incorporate multiple materials. It is fast and cost effective [64, 65].

4.5.1.4 Digital Light Processing (DLP)

The DLP printer operates in a similar way compared to the SLA, except that it uses projector technology for photopolymerization and then presents significantly faster printing time. However, the resolution may be reduced, depending on the quality of the projector and the material used.

4.6 Computer-Guided Implant Surgery Workflow

Correct implant positioning is essential to obtain favorable esthetic and prosthetic outcomes as well as long-term stability of peri-implant hard and soft tissues. Moreover, optimal implant position allows for a screw-retained prosthesis that are retrievable and together with an adequate design will improve patient ability to perform home care [66].

The use of CBCT and IOS revolutionized the way we practice implant treatment planning. The superimposed images enable virtual implant planning, while taking the surrounding anatomic structures and future prosthetic needs into consideration [67]. The virtual implant locations can be translated into a surgical guide [16, 68]. Recent studies demonstrated that computer-guided surgery (CGS) should be considered to improve accuracy for multiple-implant cases in complete or partial edentulism [15]. CGS may result in a higher implant survival rate and comparable long-term cost to non-guided implant placement [69]. CGS can facilitate flapless implant surgeries for patient satisfaction, a reduction in treatment time, and decreased postoperative discomfort [70, 71].

4.6.1 Double CBCT Scan Technique

This method requires 2 CBCT scans for treatment planning [24, 72]. The first scan is taken when the patient wears the radiographic guide and the second scan is taken only on the radiographic guide (Fig. 4.10 top panel). The guide, representing the ideal future prosthesis, must contain radiopaque marks, e.g., gutta-percha (Fig. 4.10 middle panel). A planning software is then used for virtual implant placement (Fig. 4.10 bottom panel). Once the implants are virtually placed a surgical guide can be made.

At the surgical site, the guide is fixated with specific pins and screws in the patient jaw (top row in Fig. 4.11). With the surgical template in place, a guided surgical implant kit of the implant system selected is used for osteotomy and implant placement (bottom row in Fig. 4.11). In the fully guided protocol, implant placement is also guided and stops in the screwdriver allow precise implant placement also in the corono-apical direction (Fig. 4.12).

4.6.2 Limitations of the Double CBCT Scan Technique

The limitations pertain to the extra cost, increased radiation exposure and time when a new radiopaque template has to be made and the degree of accuracy to match the 2 scans [7, 27].

4.6.3 Optical Scanning Technique

Image fusion of the STL data, obtained from the optical scanning, with the DICOM data, obtained from the CBCT, is performed by matching the common reference points (Fig. 4.13) [9, 28]. The STL data can be obtained either from casts, wax-ups, or directly with the use of IOS. STL data provide prosthesis locations plus surface of surrounding tissues and DICOM data provide bone locations. Optimal implant positioning is then planned on software accordingly. Utilizing this digital application eliminates analogue preoperative waxing-up since a virtual/digital wax-up can be designed (Fig. 4.14).

The guide can then be virtually fabricated and exported in .STL file to be manufactured by 3D printing or milling. The introduction of optical scanning

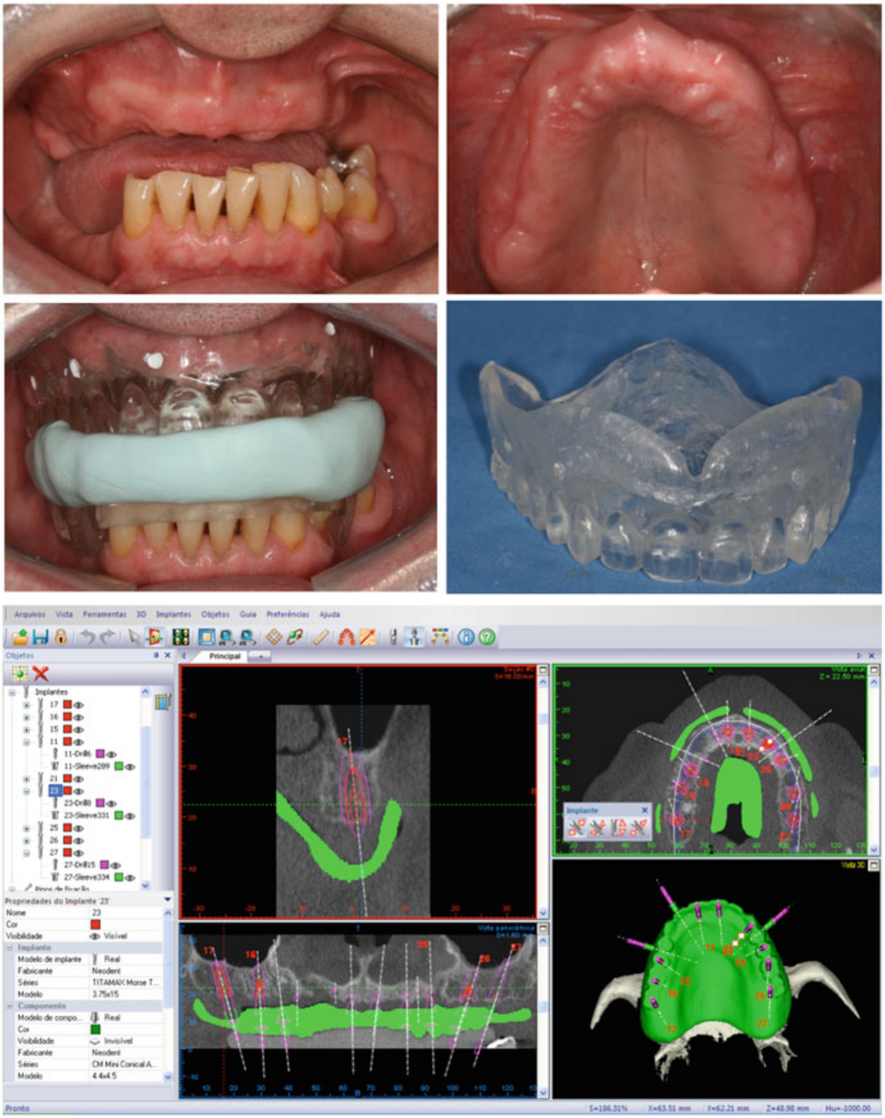

Fig. 4.10 Demonstration of the double scan technique. Top row: the maxillary edentulous arch to be restored. Middle row: a template guide in mouth and extra-orally for dual CBCT scans. Bottom row: screenshots of the prosthetically driven implant planning on software at different view planes

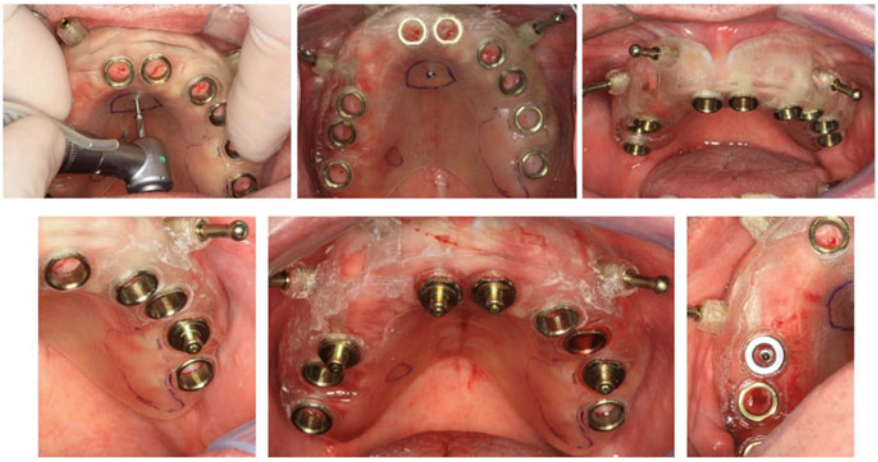

Fig. 4.11 Guide fixation using fixation screws and pins (top row, left and middle panel); surgical guided fixated for flapless implant surgery (top row, right panel); stops in the surgical template to avoid movements of the surgical guide and consequently deviations (bottom row, left and middle panel); implant in position after fully guided placement (bottom row, right panel)

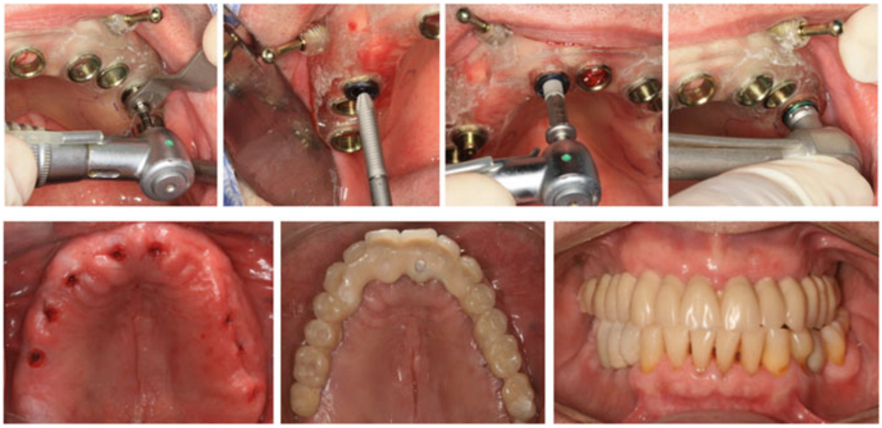

Fig. 4.12 Demonstration of the fully guided protocol. Top: osteotomy and implant placement are assisted by the guide. Bottom: immediate interim prosthesis is delivered

images was then a remarkable step to eliminate a radiographic template fabrication and a second CBCT scan. The steps are summarized below [18]:

1. Take intraoral digital scans of the maxilla, mandible, and maximal intercuspal position with an intraoral scanner. Save the digital impression as *example.stl*.
2. Open *example.stl* into a Guided Treatment Planning Software (e.g., Blue Sky Plan v.4.0; Blue Sky Bio) and align with the digital file in .DICOM including the hard tissue information (Fig. 4.13).

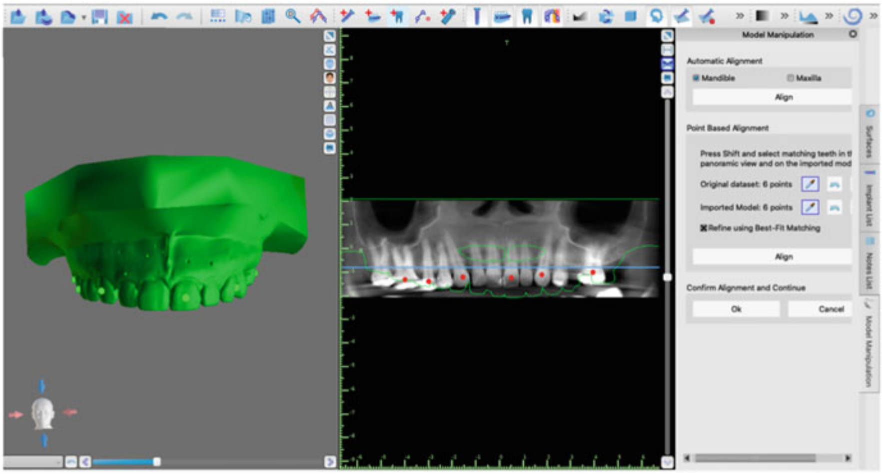

Fig. 4.13 Matching the STL with the DICOM data in specific implant planning software

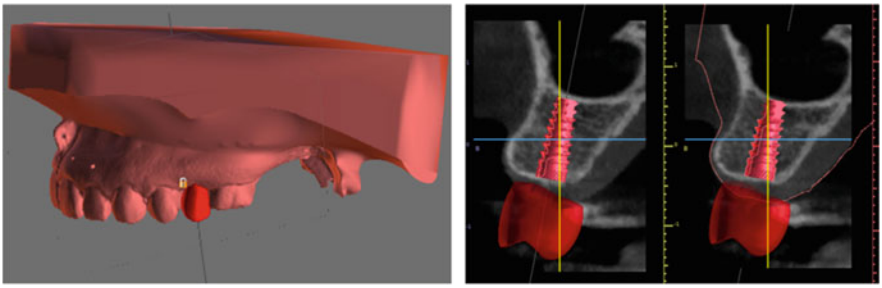

Fig. 4.14 An example of virtual wax-up on software. After merging the STL and DICOM data sets, a virtual restoration at tooth #13 location is placed and the implant position is planned accordingly

3. Virtually place the implant in optimal 3D position and create a virtual guide on software (Fig. 4.14).
4. Export the *example.stl* of the guide to be 3D printed or milled.
5. Verify the guide accuracy in the oral cavity and use in the surgery (Fig. 4.15).

4.6.4 Limitations of the Optical Scanning Technique

Previous reports stated that patients must have at least 6 remaining teeth distributed in 2 quadrants to allow for accurate imaging matching [73, 74]. In complete edentulous cases, a tomographic guide or the existing denture might be used [7, 75]. The high introductory costs of intraoral scanners could be potentially a barrier. Soft tissue features cannot be evaluated with this method.

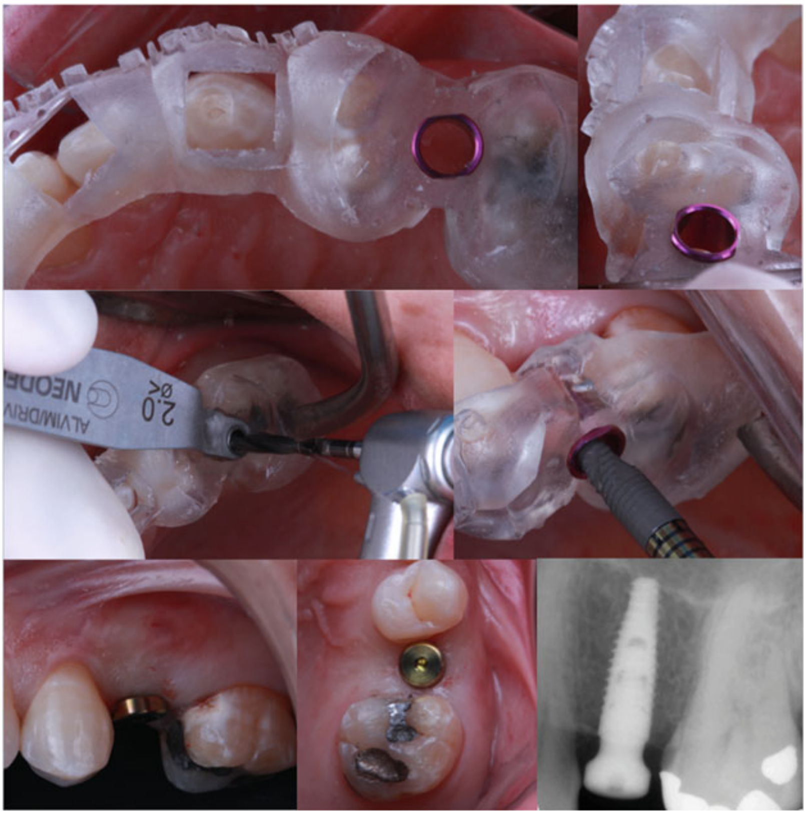

Fig. 4.15 Surgical steps using a tooth-supported guide in a fully digital workflow. Windows in the surgical guide allows better visualization of template adaptation on teeth (top row). Guided drilling sequence and implant placement (middle row) and final implant position clinically and radiographically (bottom row)

4.6.5 Accuracy of Computer-Guided Implant Surgery

Recent literature [38] shows encouraging outcomes for the CGS accuracy using a complete digital workflow for tooth-supported guides and are summarized in Table 4.9. Bone-supported guides showed a statistically significant greater deviation [76] and therefore was excluded from the analysis in this chapter. Some factors may influence the accuracy, including the number of unrestored teeth, implant location, implant diameter, and cortical interference [20].

Table 4.9 Summary of the accuracy of CGS using tooth-supported guides in a fully digital workflow

Digital intraoral scanning systems									
Author	Study design	Number of implants/ patients	Implant system	IOS utilized	Accuracy evaluation method	Results Angular deviation	Global deviation (shoulder)	Global deviation (apex)	Corono-apical deviation
Tallarico et al. [78]	RCT	28 implants/10 patients	Osstem TSIII, Osstem, Seoul, South Korea	CS 3600 intraoral scanner (Carestream Dental, Atlanta, GA, USA)	Comparison[a]	2.25 ± 1.41°	N/A	N/A	0.58 ± 0.44 mm
Tallarico et al. [77]	Prospective	119 implants/39 patients	Osstem TSIII, Osstem, Seoul, South Korea	3M true definition scanner	Comparison	1.43 ± 1.98°	N/A	N/A	0.42 ± 0.37 mm
Derksen et al. [20]	Prospective	145 implants/66 patients	Straumann tissue level	3M true definition scanner	Comparison	2.72 ± 1.42°	0.75 ± 0.34 mm	1.06 ± 0.44 mm	N/A
Smitkarn et al. [79]	RCT	30 implants/patients	Bone level Straumann	TRIOS (3Shape)	Superposition[b]	3.1 ± 2.3°	1 + 0.6 mm	1.3 ± 0.6 mm	0.7 ± 0.6 mm
Skjerven et al. [80]	Prospective	27 implants/20 patients	19 Astra Tech EV (Dentsply implants) and 8 Straumann bone level	TRIOS (3Shape)	Comparison	3.85 ± 1.83°	1.05 ± 0.59 mm	1.63 ± 1.05 mm	N/A
Kiatkroekkrai et al. [81]	RCT	30 implants/20 patients	Bone Level Straumann	TRIOS (3Shape)	Superposition	2.41° ± 1.47°	0.87 ± 0.49 mm	1.10 ± 0.53 mm	0.58 ± 0.47 mm

RCT, randomized clinical trial
[a]Comparison of .STL files from planned position and final position (obtained with IOS)
[b]Superimposing post CBCT images with planned positions

References

1. Kapos T, Evans C. CAD/CAM technology for implant abutments, crowns, and superstructures. Int J Oral Maxillofac Implants. 2014;29 Suppl:117–36. ISSN: 1942-4434 (Electronic) 0882-2786 (Linking). https://doi.org/10.11607/jomi.2014suppl.g2.3. https://www.ncbi.nlm.nih.gov/pubmed/24660194
2. Strub JR, Rekow ED, Witkowski S. Computer-aided design and fabrication of dental restorations: current systems and future possibilities. J Am Dent Assoc. 2006;137(9):1289–96. ISSN: 0002-8177 (Print) 0002-8177 (Linking). https://doi.org/10.14219/jada.archive.2006.0389. https://www.ncbi.nlm.nih.gov/pubmed/16946436
3. Abduo J, Lyons K. Rationale for the use of CAD/CAM technology in implant prosthodontics. Int J Dent. 2013;2013:768121. ISSN: 1687-8728 (Print) 1687-8728 (Linking). https://doi.org/10.1155/2013/768121. https://www.ncbi.nlm.nih.gov/pubmed/23690778
4. Ahmed KE, et al. Performance and perception of dental students using three intraoral CAD/CAM scanners for full-arch scanning. J Prosthodont Res. 2019;632:167–72. ISSN: 2212-4632 (Electronic) 1883-1958 (Linking). https://doi.org/10.1016/j.jpor.2018.11.003. https://www.ncbi.nlm.nih.gov/pubmed/30528397
5. Al-Moraissi E, et al. Does intraoperative perforation of Schneiderian membrane during sinus lift surgery causes an increased the risk of implants failure?: a systematic review and meta regression analysis. Clin Implant Dent Relat Res. 2018;20(5):882–9. ISSN: 1523-0899. https://doi.org/10.1111/cid.12660.
6. Alsharbaty MHM, et al. A clinical comparative study of 3-dimensional accuracy between digital and conventional implant impression techniques. J Prosthodont. 2019;28(4):e902–8. ISSN: 1532-849X (Electronic) 1059-941X (Linking). https://doi.org/10.1111/jopr.12764. https://www.ncbi.nlm.nih.gov/pubmed/29423969
7. An X, Yang HW, Choi BH. Digital workflow for computer-guided implant surgery in edentulous patients with an intraoral scanner and old complete denture. J Prosthodont. 2019;28(6):715–8. ISSN: 1532-849X (Electronic) 1059-941X (Linking). https://doi.org/10.1111/jopr.13073. https://www.ncbi.nlm.nih.gov/ubmed/31087422
8. Andriessen FS, et al. Applicability and accuracy of an intraoral scanner for scanning multiple implants in edentulous mandibles: a pilot study. J Prosthet Dent. 2017;111(3):186–94. ISSN: 1097-6841 (Electronic) 0022-3913 (Linking). https://doi.org/10.1016/j.prosdent.2013.07.010. https://www.ncbi.nlm.nih.gov/pubmed/24210732
9. Arcuri L, et al. Full digital workflow for implant-prosthetic rehabilitations: a case report. Oral Implantol (Rome) 2015;8(4):114–21. ISSN: 1974-5648 (Print) 1974-5648 (Linking). https://doi.org/10.11138/orl/2015.8.4.114. https://www.ncbi.nlm.nih.gov/pubmed/28042423
10. Barazanchi A, et al. Additive technology: update on current materials and applications in dentistry. J Prosthodont. 2017;26(2):156–63. ISSN: 1532-849X (Electronic) 1059-941X (Linking). https://doi.org/10.1111/jopr.12510. https://www.ncbi.nlm.nih.gov/pubmed/27662423
11. Rios HF, Borgnakke WS, Benavides E. The use of cone-beam computed tomography in management of patients requiring dental implants: an American Academy of Periodontology best evidence review. J Periodontol. 2017;88(10):946–59
12. Tyndall DA, et al. Position statement of the American Academy of Oral and Maxillofacial Radiology on selection criteria for the use of radiology in dental implantology with emphasis on cone beam computed tomography. Oral Surg Oral Med Oral Pathol Oral Radiol. 2012;113(6):817–26. ISSN: 2212-4411 (Electronic). https://doi.org/10.1016/j.oooo.2012.03.005. http://www.ncbi.nlm.nih.gov/pubmed/22668710
13. Boyne PJ, James RA. Grafting of the maxillary sinus floor with autogenous marrow and bone. J Oral Surg. 1980;38(8):613–6. ISSN: 0022-3255 (Print) 0022-3255 (Linking). https://www.ncbi.nlm.nih.gov/pubmed/6993637
14. Chan HL, Wang HL. Sinus pathology and anatomy in relation to complications in lateral window sinus augmentation. Implant Dent. 2011;20(6):406–12. ISSN: 1538-2982 (Electronic) 1056-6163 (Linking). https://doi.org/10.1097/ID.0b013e3182341f79. https://www.ncbi.nlm.nih.gov/pubmed/21986451

15. Choi W, et al. Freehand versus guided surgery: factors influencing accuracy of dental implant placement. Implant Dent. 2017;26(4):500–9. ISSN: 1538-2982 (Electronic) 1056-6163 (Linking). https://doi.org/10.1097/ID.0000000000000620. https://www.ncbi.nlm.nih.gov/pubmed/28731896
16. D'Haese J, et al. Current state of the art of computer-guided implant surgery. Periodontol 2000. 2017;73(1):121–33. ISSN: 1600-0757 (Electronic) 0906-6713 (Linking). https://doi.org/10.1111/prd.12175. https://www.ncbi.nlm.nih.gov/pubmed/28000275
17. Dawood A, et al. 3D printing in dentistry. Br Dent J. 2015;219(11):521–9. ISSN: 1476-5373 (Electronic) 0007-0610 (Linking). https://doi.org/10.1038/sj.bdj.2015.914. https://www.ncbi.nlm.nih.gov/pubmed/26657435
18. de Siqueira RAC, et al. Using digital technique to obtain the ideal soft tissue contour in immediate implants with provisionalization. Implant Dent. 2019;28(4):411–6. ISSN: 1538-2982 (Electronic) 1056-6163 (Linking). https://doi.org/10.1097/ID.0000000000000914. https://www.ncbi.nlm.nih.gov/pubmed/31157756
19. Delize V, et al. Intrasubject comparison of digital vs. conventional workflow for screw-retained single-implant crowns: Prosthodontic and patient-centered outcomes. Clin Oral Implants Res. 2019. ISSN: 1600-0501 (Electronic) 0905-7161 (Linking). https://doi.org/10.1111/clr.13494. https://www.ncbi.nlm.nih.gov/pubmed/31183902
20. Derksen W, et al. The accuracy of computer guided implant surgery with tooth supported, digitally designed drill guides based on CBCT and intraoral scanning. A prospective cohort study. Clin Oral Implants Res. 2019. ISSN: 1600-0501 (Electronic) 0905-7161 (Linking). https://doi.org/10.1111/clr.13514. https://www.ncbi.nlm.nih.gov/pubmed/31330566
21. Di Fiore A, et al. Full arch digital scanning systems performances for implant-supported fixed dental prostheses: a comparative study of 8 intraoral scanners. J Prosthodont Res. (2019). ISSN: 2212-4632 (Electronic) 1883-1958 (Linking). https://doi.org/10.1016/j.jpor.2019.04.002. https://www.ncbi.nlm.nih.gov/pubmed/31072730
22. Elian N, et al. Distribution of the maxillary artery as it relates to sinus floor augmentation. Int J Oral Maxillofac Implants. 2005;20(5):784–7. ISSN: 0882-2786 (Print) 0882-2786 (Linking). https://www.ncbi.nlm.nih.gov/pubmed/16274154
23. Ender A, Mehl A. Accuracy of complete-arch dental impressions: a new method of measuring trueness and precision. J Prosthet Dent. 2013;109(2):121–8. ISSN: 1097-6841 (Electronic) 0022-3913 (Linking). https://doi.org/10.1016/S0022-3913(13)60028-1. https://www.ncbi.nlm.nih.gov/pubmed/23395338
24. Ersoy AE, et al. Reliability of implant placement with stereolithographic surgical guides generated from computed tomography: clinical data from 94 implants. J Periodontol. 2008;79(8):1339–45. ISSN: 0022-3492 (Print) 0022-3492 (Linking). https://doi.org/10.1902/jop.2008.080059. https://www.ncbi.nlm.nih.gov/pubmed/18672982
25. Flugge T, et al. The accuracy of different dental impression techniques for implant-supported dental prostheses: a systematic review and meta4.7 References 113 analysis. Clin Oral Implants Res. 2018;29 Suppl 16:374–92. ISSN: 0905-7161. https://doi.org/10.1111/clr.13273
26. Flugge TV, et al. Precision of dental implant digitization using intraoral scanners. Int J Prosthodont. 2016;29(3):277–83. ISSN: 0893-2174 (Print) 0893-2174 (Linking). https://doi.org/10.11607/ijp.4417. https://www.ncbi.nlm.nih.gov/pubmed/27148990
27. Flugge TV, et al. Three-dimensional plotting and printing of an implant drilling guide: simplifying guided implant surgery. J Oral Maxillofac Surg. 2013;71(8):1340–6. ISSN: 1531-5053 (Electronic) 0278-2391 (Linking). https://doi.org/10.1016/j.joms.2013.04.010. https://www.ncbi.nlm.nih.gov/pubmed/23866950
28. De Vico G, et al. A novel workflow for computer guided implant surgery matching digital dental casts and CBCT scan. Oral Implantol. 2016;9(1):33–48. ISSN: 1974-5648 (Print) 1974-5648 (Linking). https://doi.org/10.11138/orl/2016.9.1.033. https://www.ncbi.nlm.nih.gov/pubmed/28042429
29. Mangano F, et al. Intraoral scanners in dentistry: a review of the current literature. BMC Oral Health. 2017;17(1):149. ISSN: 1472-6831 (Electronic) 1472-6831 (Linking). https://doi.org/10.1186/s12903-017-0442-x. https://www.ncbi.nlm.nih.gov/pubmed/29233132

30. Ting-Shu S, Jian S. Intraoral digital impression technique: a review. J Prosthodont. 2015;24(4):313–21. ISSN: 1059-941x. https://doi.org/10.1111/jopr.12218
31. Zimmermann M, et al. Intraoral scanning systems – a current overview. Int J Comput Dent. 2015;18(2):101–29. ISSN: 1463-4201 (Print) 1463-4201 (Linking). https://www.ncbi.nlm.nih.gov/pubmed/26110925
32. Joda T, Bragger U. Time-efficiency analysis comparing digital and conventional workflows for implant crowns: a prospective clinical crossover trial. Int J Oral Maxillofac Implants. 2015;30(5):1047–53. ISSN: 1942-4434 (Electronic) 0882-2786 (Linking). https://doi.org/10.11607/jomi.3963. https://www.ncbi.nlm.nih.gov/pubmed/26394340
33. Renne W, et al. Evaluation of the accuracy of 7 digital scanners: an in vitro analysis based on 3-dimensional comparisons. J Prosthet Dent. 2017;118(1):36–42. ISSN: 1097-6841 (Electronic) 0022-3913 (Linking). https://doi.org/10.1016/j.prosdent.2016.09.024. https://www.ncbi.nlm.nih.gov/pubmed/28024822
34. Prudente MS, et al. Influence of scanner, powder application, and adjustments on CAD-CAM crown misfit. J Prosthet Dent. 2018;119(3):377–383. ISSN: 1097-6841 (Electronic) 0022-3913 (Linking). https://doi.org/10.1016/j.prosdent.2017.03.024. https://www.ncbi.nlm.nih.gov/pubmed/28689912
35. Kapos T, et al. Computer-aided design and computer-assisted manufacturing in prosthetic implant dentistry. Int J Oral Maxillofac Implants. 2009;24 Suppl:110–7. ISSN: 0882-2786 (Print) 0882-2786 (Linking). https://www.ncbi.nlm.nih.gov/pubmed/19885438
36. Lee SJ, et al. Accuracy of digital versus conventional implant impressions. Clin Oral Implants Res. 2015;26(6):715–9. ISSN: 1600-0501 (Electronic) 0905-7161 (Linking). https://doi.org/10.1111/clr.12375. https://www.ncbi.nlm.nih.gov/pubmed/24720423
37. Serag M, et al. A comparative study of the accuracy of dies made from digital intraoral scanning vs. elastic impressions: an in vitro study. J Prosthodont. 2018;27(1):88–93. ISSN: 1532-849X (Electronic) 1059-941X (Linking). https://doi.org/10.1111/jopr.12481. https://www.ncbi.nlm.nih.gov/pubmed/27149542
38. Siqueira R, Chen Z, Galli M, Saleh I, Wang H-L, Chan H-L. Does a fully digital workflow improve the accuracy of computer-assisted implant surgery in partially edentulous patients? A systematic review of clinical trials. Clin Implant Dent Relat Res. 2020;1–12. https://doi.org/10.1111/cid.12937
39. Marghalani A, et al. Digital versus conventional implant impressions for partially edentulous arches: an evaluation of accuracy. J Prosthet Dent. 2018;119(4):574–9. ISSN: 1097-6841 (Electronic) 0022-3913 (Linking). https://doi.org/10.1016/j.prosdent.2017.07.002. https://www.ncbi.nlm.nih.gov/pubmed/28927923
40. Papaspyridakos P, et al. Digital versus conventional implant impressions for edentulous patients: accuracy outcomes. Clin Oral Implants Res. 2016;27(4);465–72. ISSN: n (Electronic) 0905-7161 (Linking). https://doi.org/10.1111/clr.12567. https://www.ncbi.nlm.nih.gov/pubmed/25682892
41. Kim JE, et al. Accuracy of intraoral digital impressions using an artificial landmark. J Prosthet Dent. 2017;117(6):755–61. ISSN: 1097-6841 (Electronic) 0022-3913 (Linking). https://doi.org/10.1016/j.prosdent.2016.09.016. https://www.ncbi.nlm.nih.gov/pubmed/27863856
42. Iturrate M, et al. Accuracy analysis of complete-arch digital scans in edentulous arches when using an auxiliary geometric device". J Prosthet Dent. 2019;121(3):447–54. ISSN: 1097-6841 (Electronic) 0022-3913 (Linking). https://doi.org/10.1016/j.prosdent.2018.09.017. https://www.ncbi.nlm.nih.gov/pubmed/30554826
43. Lin WS, et al. Use of intraoral digital scanning for a CAD/CAM-fabricated milled bar and superstructure framework for an implant-supported, removable complete dental prosthesis. J Prosthet Dent. 2015;113(6):509–15. ISSN: 1097-6841 (Electronic) 0022-3913 (Linking). https://doi.org/10.1016/j.prosdent.2015.01.014. https://www.ncbi.nlm.nih.gov/pubmed/25862270
44. Lin WS, et al. Use of digital data acquisition and CAD/CAM technology for the fabrication of a fixed complete dental prosthesis on dental implants. J Prosthet Dent. 2014;111(1):1–5. ISSN: 1097-6841 (Electronic) 0022-3913 (Linking). https://doi.org/10.1016/j.prosdent.2013.04.010. https://www.ncbi.nlm.nih.gov/pubmed/24189115

45. Güth J-F, et al. Accuracy of digital models obtained by direct and indirect data capturing. Clin Oral Investig. 2013;17(4):1201–8
46. Garino F, Garino B. The OrthoCAD iOC intraoral scanner: a six-month user report. J Clin Orthod. 2011;45(3):161–4. ISSN: 0022-3875 (Print) 0022-3875 (Linking). https://www.ncbi.nlm.nih.gov/pubmed/21785200
47. Garino F, Garino GB, Castroflorio T. The iTero intraoral scanner in Invisalign treatment: a two-year report. J Clin Orthod. 2014;48(2):98–106. ISSN: 0022-3875 (Print) 0022-3875 (Linking). https://www.ncbi.nlm.nih.gov/pubmed/24763683
48. Yuzbasioglu E, et al. Comparison of digital and conventional impression techniques: evaluation of patients' perception, treatment comfort, effectiveness and clinical outcomes. BMC Oral Health. 2014;14:10. ISSN: 1472-6831 (Electronic) 1472-6831 (Linking). https://doi.org/10.1186/1472-6831-14-10. https://www.ncbi.nlm.nih.gov/pubmed/24479892
49. Pan S, et al. Time efficiency and quality of outcomes in a model-free digital workflow using digital impression immediately after implant placement: a double-blind self-controlled clinical trial. Clin Oral Implants Res. 2019;30(7):617–26. ISSN: 1600-0501 (Electronic) 0905-7161 (Linking). https://doi.org/10.1111/clr.13447. https://www.ncbi.nlm.nih.gov/pubmed/31021451
50. Schepke U, et al. Digital versus analog complete-arch impressions for single-unit premolar implant crowns: Operating time and patient preference. J Prosthet Dent. 2015;114(3):403–406 e401. doi:10.1016/j.prosdent.2015.04.003
51. Wismeijer D, et al. Patients' preferences when comparing analogue implant impressions using a polyether impression material versus digital impressions (Intraoral Scan) of dental implants. Clin Oral Implants Res. 2014;25(10):1113–8. ISSN: 1600-0501 (Electronic) 0905-7161 (Linking). https://doi.org/10.1111/clr.12234. https://www.ncbi.nlm.nih.gov/pubmed/23941118
52. Joda T, Bragger U. Patient-centered outcomes comparing digital and conventional implant impression procedures: a randomized crossover trial.Clin Oral Implants Res. 2016;27(12):e185–9. ISSN: 1600-0501 (Electronic) 0905-7161 (Linking). https://doi.org/10.1111/clr.12600. https://www.ncbi.nlm.nih.gov/pubmed/25864771
53. Guo DN, et al. Clinical Efficiency and Patient Preference of Immediate Digital Impression after Implant Placement for Single Implant-Supported Crown. Chin J Dent Res. 2019;22(1):21–28. doi:10.3290/j.cjdr.a41771
54. Lee SJ, Gallucci GO. Digital vs. conventional implant impressions: efficiency outcomes. Clin Oral Implants Res. 2013;24(1):111–5. ISSN: 1600-0501 (Electronic) 0905-7161 (Linking). https://doi.org/10.1111/j.1600-0501.2012.02430.x. https://www.ncbi.nlm.nih.gov/pubmed/22353208
55. Marti AM, et al. Comparison of digital scanning and polyvinyl siloxane impression techniques by dental students: instructional efficiency and attitudes towards technology. Eur J Dent Educ. 2017;21(3):200–5. ISSN: 1600-0579 (Electronic) 1396-5883 (Linking). https://doi.org/10.1111/eje.12201. https://www.ncbi.nlm.nih.gov/pubmed/26960967
56. Joda T, et al. Time efficiency, difficulty, and operator's preference comparing digital and conventional implant impressions: a randomized controlled trial. Clin Oral Implants Res. 2017;28(10):1318–1323. ISSN: 1600-0501 (Electronic) 0905-7161 (Linking). https://doi.org/10.1111/clr.12982. https://www.ncbi.nlm.nih.gov/pubmed/27596805
57. Kim J, et al. Comparison of experience curves between two 3-dimensional intraoral scanners. J Prosthet Dent. 2016;116(2):221–30. ISSN: 1097-6841 (Electronic) 0022-3913 (Linking). https://doi.org/10.1016/j.prosdent.2015.12.018. https://www.ncbi.nlm.nih.gov/pubmed/27061634
58. Lim JH, et al. Comparison of digital intraoral scanner reproducibility and image trueness considering repetitive experience. J Prosthet Dent. 2018;119(2):225–32. ISSN: 1097-6841 (Electronic) 0022-3913 (Linking). https://doi.org/10.1016/j.prosdent.2017.05.002. https://www.ncbi.nlm.nih.gov/pubmed/28689906
59. Patzelt SB, et al. Assessing the feasibility and accuracy of digitizing edentulous jaws. J Am Dent Assoc. 2013;144(8):914–20. ISSN: 1943-4723 (Electronic) 0002-8177 (Linking). https://doi.org/10.14219/jada.archive.2013.0209. https://www.ncbi.nlm.nih.gov/pubmed/23904578

60. Runkel C, et al. Digital impressions in dentistry-accuracy of impression digitalisation by desktop scanners. Clin Oral Investig. 2019. ISSN: 1436-3771 (Electronic) 1432-6981 (Linking). https://doi.org/10.1007/s00784-019-02995-w. https://www.ncbi.nlm.nih.gov/pubmed/31302771
61. Resnick CM, et al. Is it cost effective to add an intraoral scanner to an oral and maxillofacial surgery practice? J Oral Maxillofac Surg. 2019;77(8):1687–94. ISSN: 1531-5053 (Electronic) 0278-2391 (Linking). https://doi.org/10.1016/j.joms.2019.03.011. https://www.ncbi.nlm.nih.gov/pubmed/30991020
62. Son K, Lee WS, Lee KB. Prediction of the learning curves of 2 dental CAD software programs. J Prosthet Dent. 2019;121(1):95–100. ISSN: 1097-6841 (Electronic) 0022-3913 (Linking). https://doi.org/10.1016/j.prosdent.2018.01.004. https://www.ncbi.nlm.nih.gov/pubmed/30017157
63. Sommacal B, et al. Evaluation of two 3D printers for guided implant surgery. Int J Oral Maxillofac Implants. 2018;33(4):743–6. ISSN: 1942-4434 (Electronic) 0882-2786 (Linking). https://doi.org/10.11607/jomi.6074. https://www.ncbi.nlm.nih.gov/pubmed/29543930
64. Berry E, et al. Preliminary experience with medical applications of rapid prototyping by selective laser sintering. Med Eng Phys. 1997;19(1):90–6. ISSN: 1350-4533 (Print) 1350-4533 (Linking). https://www.ncbi.nlm.nih.gov/pubmed/9140877
65. Tan KH, et al. Scaffold development using selective laser sintering of polyetheretherketone-hydroxyapatite biocomposite blends. Biomaterials. 2003;24(18):3115–23. ISSN: 0142-9612 (Print) 0142-9612 (Linking). https://doi.org/10.1016/s0142-9612(03)00131-5. https://www.ncbi.nlm.nih.gov/pubmed/12895584
66. Lambert FE, et al. Descriptive analysis of implant and prosthodontic survival rates with fixed implant-supported rehabilitations in the edentulous maxilla. J Periodontol. 2009;80(8):1220–30. ISSN: 0022-3492 (Print) 0022-3492 (Linking). https://doi.org/10.1902/jop.2009.090109. https://www.ncbi.nlm.nih.gov/pubmed/19656021
67. Ganz SD. Presurgical planning with CT-derived fabrication of surgical guides. J Oral Maxillofac Surg. 2005;63(9 Suppl 2):59–71. ISSN: 0278-2391 (Print) 0278-2391 (Linking). https://doi.org/10.1016/j.joms.2005.05.156. https://www.ncbi.nlm.nih.gov/pubmed/16125016
68. Vercruyssen M, et al. Computer-supported implant planning and guided surgery: a narrative review. Clin Oral Implants Res. 2015;26(Suppl 11):69–76. ISSN: 1600-0501 (Electronic) 0905-7161 (Linking). https://doi.org/10.1111/clr.12638. https://www.ncbi.nlm.nih.gov/pubmed/26385623
69. Ravida A, et al. Clinical outcomes and cost effectiveness of computer-guided versus conventional implant-retained hybrid prostheses: a long-term retrospective analysis of treatment protocols. J Periodontol. 2018;89(9):1015–24. ISSN: 1943-3670 (Electronic) 0022-3492 (Linking). https://doi.org/10.1002/JPER.18-0015. https://www.ncbi.nlm.nih.gov/pubmed/29761505
70. Hammerle CH, et al. Consensus statements and recommended clinical procedures regarding computer-assisted implant dentistry. Int J Oral Maxillofac Implants. 2009;24 Suppl:126–31. ISSN: 0882-2786 (Print) 0882-2786 (Linking). https://www.ncbi.nlm.nih.gov/pubmed/19885440
71. Moraschini V, et al. Implant survival rates, marginal bone level changes, and complications in full-mouth rehabilitation with flapless computer-guided surgery: a systematic review and meta-analysis. Int J Oral Maxillofac Surg. 2015;44(7):892–901. ISSN: 1399-0020 (Electronic) 0901-5027 (Linking). https://doi.org/10.1016/j.ijom.2015.02.013. https://www.ncbi.nlm.nih.gov/pubmed/25790741
72. Ramasamy M, et al. Implant surgical guides: From the past to the present. J Pharm Bioallied Sci. 2013;5(Suppl 1):S98–102. ISSN: 0976-4879 (Print) 0975-7406 (Linking). https://doi.org/10.4103/0975-7406.113306. https://www.ncbi.nlm.nih.gov/pubmed/23946587
73. De Vico G, et al. Computer-assisted virtual treatment planning combined with flapless surgery and immediate loading in the rehabilitation of partial edentulies. Oral Implantol. 2012;5(1):3–10. ISSN: 1974-5648 (Print) 1974-5648 (Linking). https://www.ncbi.nlm.nih.gov/pubmed/23285400

74. van Steenberghe D, et al. A custom template and definitive prosthesis allowing immediate implant loading in the maxilla: a clinical report. Int J Oral Maxillofac Implants. 2002;17(5):663–70. ISSN: 0882-2786 (Print) 0882-2786 (Linking). https://www.ncbi.nlm.nih.gov/pubmed/12381066
75. Oh JH, et al. Digital workflow for computer-guided implant surgery in edentulous patients: a case report. J Oral Maxillofac Surg. 2017;75(12):2541–9. ISSN: 1531-5053 (Electronic) 0278-2391 (Linking). https://doi.org/10.1016/j.joms.2017.08.008. https://www.ncbi.nlm.nih.gov/pubmed/28881181
76. Raico Gallardo YN, et al. Accuracy comparison of guided surgery for dental implants according to the tissue of support: a systematic review and meta-analysis. Clin Oral Implants Res. 2017;28(5):602–12. ISSN: 1600-0501 (Electronic) 0905-7161 (Linking). https://doi.org/10.1111/clr.12841. https://www.ncbi.nlm.nih.gov/pubmed/27062555
77. Tallarico, M. et al. Accuracy of computer-assisted template-based implant placement using conventional impression and scan model or intraoral digital impression: A randomised controlled trial with 1 year of follow-up. Int J Oral Implantol (Berl). 2019;12(2):197–206.
78. Tallarico M, et al. Accuracy of newly developed sleeve-designed templates for insertion of dental implants: A prospective multicenters clinical trial. Clin Implant Dent Relat Res. 2019;21:108–13. https://doi.org/10.1111/cid.12704
79. Smitkarn P, et al. The accuracy of single-tooth implants placed using fully digital-guided surgery and freehand implant surgery. J Clin Periodontol. 2019;46:949–57. https://doi.org/10.1111/jcpe.13160.
80. Skjerven H, et al. In vivo accuracy of implant placement using a full digital planning modality and stereolithographic guides. Int J Oral Maxillofac Implants. 2019;34:124–32. https://doi.org/110.11607/jomi.16939.
81. Kiatkroekkrai P, et al. Accuracy of implant position when placed using static computer-assisted implant surgical guides manufactured with two different optical scanning techniques: a randomized clinical trial. Int J Oral Maxillofac Surg. 2020;49:377–83.