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Digital workflow in complete dentures: A narrative review

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ABSTRACT

Aim The aim of the present study is to review the literature evaluating the main steps required in complete denture rehabilitation in case of edentulous jaws in the digital workflow.
Methods This review was conducted using PubMed and Scopus databases. It focuses on the following clinical and laboratory steps: the impression, the registration of the centric relation, the try-in and the finalization.
Results According to the reported data in literature, impression, try-in and finalization are feasible with a complete digital approach. Registration of the centric is possible only combining the digital with the traditional one. Digital impression is accurate, but shows some limitations in the peripheral areas. The printing process, because of accuracy and its cost, can be used for the try-in of the prototype. Milling machine is more accurate than 3D printing and offers a good level of retention and of satisfaction for the patient.
Conclusions In relation to optical scanning, there are still some limitations because of the impossibility to perform selective pressure in the areas of the peripheral seal. Fully digital methods to register the centric are not described. More evidence based evidence on qualitative and quantitative results is required to validate digital denture protocols.

KEYWORDS Digital dentistry; Intraoral scanner; Edentulous jaws; Digital dentures; Complete dentures.

INTRODUCTION

Tooth loss negatively influences several aspects in patient daily life such as masticatory function, phonetics and facial appearance with dramatic consequences in their psychosocial contest (1,2).
It is a chronic condition and in 1980, the World Health Organization (WHO) provided for edentulousness a definition of the terms of impairment, disability and handicap (3).
The rehabilitation of completely edentulous patients with conventional complete dentures is still a very common and predictable treatment approach (4-5).
The conventional clinical protocol in complete denture (CD) rehabilitation provides different steps as follows (6).

- Preliminary impression, generally taken in hydrocolloid-based material.
- Functional impression, registered with individual impression tray, edging it with thermoplastic paste.
- Intermaxillary registration, determining the centric relationship and the vertical dimension.
- Teeth arrangement try-in, in order to verify aesthetic, phonetic and occlusal function.
- Delivery of the prosthesis.

However this protocol can be simplified performing different procedures at the same time, thus reducing the number of appointments (7). Different studies highlighted that "simplified technique" treatment approach, achieved valuable results in patient satisfaction (8,9).
During the last years the development of digital technologies has provided new interesting results in the state of the art in the fields of aesthetic and prosthetic dentistry (10).
The digital workflow has reported some advantages comparing to the conventional technique used for fabricating complete dentures, reducing the clinical procedures, number of visits, treatment time and costs (11).
Several manufacturers developed different approaches in order to obtain complete denture thanks to digital

protocol. Steinmassl et al. reported an overview of the different clinical denture adaptation protocols, using standardized questionnaires made directly by different manufacturers (12). After a detailed analysis, the authors concluded that available computer aided design/ computer aided manufacturing (CAD/CAM) denture fabrication systems provide several advantages, such as protocols with reduced number of sessions, and that the choice of a system should depend on the dentist's prosthodontics expertise, requirements regarding denture individualization, and patient throughput rate.

However some aspects for the complete denture construction remain essential even with the digital approach: the impression, the centric registration and the teeth arrangement try in and finally the manufacturing. In fact, to obtain a stable and retentive denture, the bearing bases have to be precise and show maximum contact with the tissues, the teeth also have to be positioned correctly in static position and the relation of jaws has to be repeatable, ensuring adhesion and cohesion forces that are mediated by a thin film of saliva (6).

Regarding the CAD/CAM technology, it is based on three basic aspects (13) which are: data acquisition, data processing and prosthesis manufacturing.

Data acquisition allows to create a "virtual master model" (which can be processed using a special dental software) that can be provided in two ways.

1) In the dental office, through the use of intra-oral scanners (IOS) that acquire information directly from the patient's oral cavity.
2) In the laboratory, through the use of extra-oral scanners that obtain information from the traditional impression or from the master model in plaster, after pouring the conventional dental impression.

The accuracy is the main parameter to evaluate the performance of a measurement method, such as the digital impression. This concept is explained in two aspects: trueness and precision. Trueness means how much a value is close to the reference value, whereas precision indicates the repeatability of the data when different scans are made and subsequently superimposed (14) (Fig. 1).

Once the dental arches of patients are obtained, the relationship between them is required. A stable and repetitive registration of the centric relation is a fundamental aspect to determine the success in CD rehabilitations (15,16). This registration of centric relation is possible using many different methods, such as the conventional method with the occlusal rims and instrumental method, like the gothic arch tracing (17). This could be a critical step for the full digital workflow, since it requires a clinical step, in particular in edentulous conditions where all the points of reference that can allow to determine the centric relationship are lost. Furthermore, it remains to be clarified how a device for recording the centric relation can be obtained starting from the intra-oral scans (that are in no relation to each other) and what is the procedure for transferring this information from the patient to the digital system. However, using dedicated software (CAD phase), the virtual models positioned in a centric relationships are used for mounting teeth digitally and for printing a digital prototype. This step is fundamental to validate with the patient all parameters set, so as to verify the centric relation and evaluate aesthetic and phonetic parameters (18). If there are no changes to make, the denture is ready for CAM finalization.

An important value in digital approach can be added with the face scanners; indeed it is possible to obtain a superimposition of different data on the facial skeleton, soft tissue, and/or dentition; it is a feasible technique to create a virtual patient under static conditions (19).

Once data have been processed, they are sent to the CAM machine tool, which can be additive (using a rapid prototyping procedure) or subtractive (computerized numerical control milling) process. The second one is a more frequently employed method to carry out the prosthetic reconstruction(20).

The first studies about digital dentures have led to the publication of the first review studies focused on patient-centered outcomes and clinical aspects of this technology (20,21,22).

To date, due to the relatively recent development of the protocols in CD, there is still a lack of evidence in the required procedures. So it is necessary a comprensive

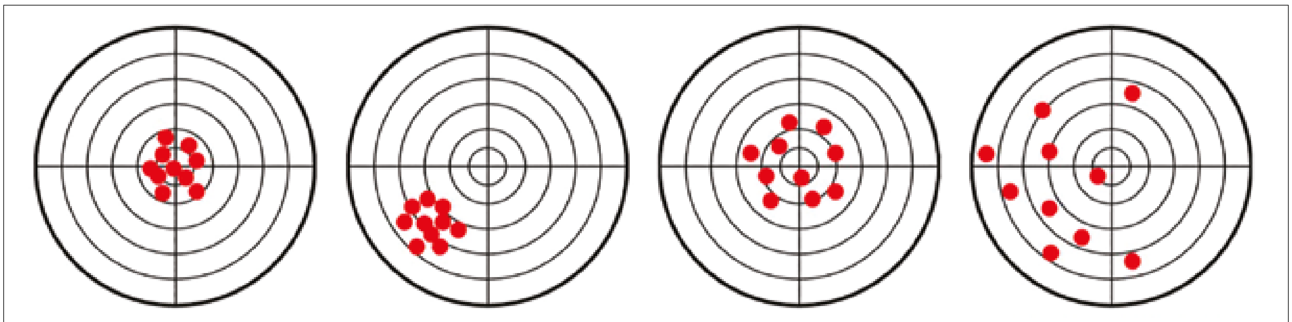

FIG. 1 Trueness is described as the closeness of agreement between the arithmetic mean of a measured subject and a known or true value. Precision is described as the closeness of agreement between test results.

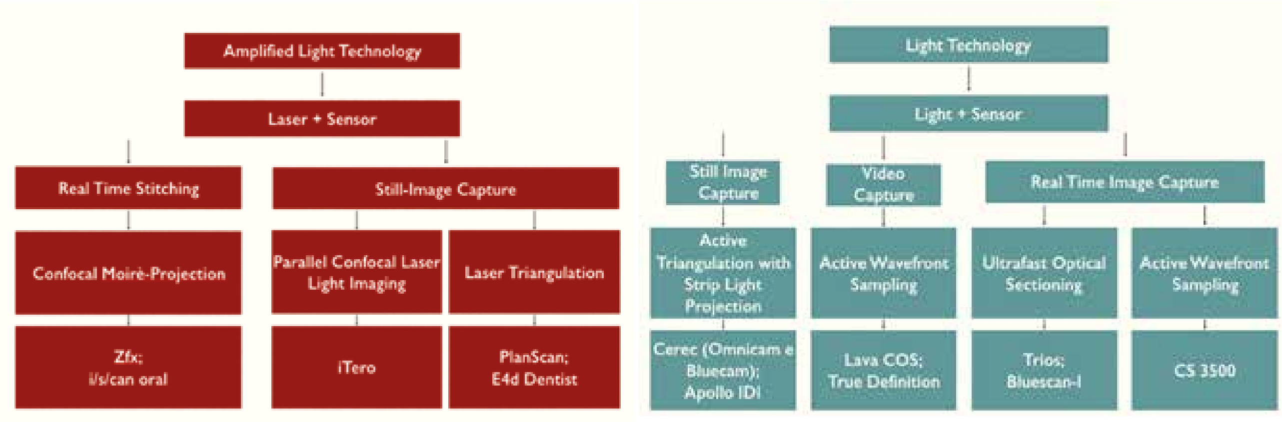

TABLE 1 Technologies of digital scanner according to "Digital Workflow in Reconstructive Dentistry", edited by: Att, Wael, Witkowski, Siegbert, Strub, Jörg R. (Hrsg.), 2019

view of the state of the art in this filed.
Thus the purpose of this paper is to analyze and summarize the main aspects of digital denture rehabilitation process comparing it to the conventional one.

METHODS

The present narrative review was conducted using PubMed and Scopus databases.
The survey collected data until the first of March 2020, only articles in English language were considered. Three fundamental steps in complete denture manufacturing processes were analyzed: tissue impression, centric registration, the try in with a prototype and the finalization.
The query terms were reported as follows.
For impression: intra-oral scanner, IOS, digital impression, edentulous jaw; the outcome evaluated was the accuracy.
For centric registration: digital centric relation, digital jaw relation; the outcomes evaluated were feasibility and repeatability.
For try in: 3D printer denture, denture prototype, digital test; the outcomes evaluated were accuracy of 3D printer and costs.
For finalization: CAD/CAM, digital denture, digital finalization denture; the outcomes evaluated were retention and patient satisfaction.
Data were collected and summarized in the results.

RESULTS

Impression

Information on the trueness and precision of IOSs are available in literature (23-26).
All intra-oral scanners work thanks to optical technologies without contact with the studied object, such as confocal microscopy (Trios-3Shape), coherent light optical tomography (E4D-D4D Technologies LLC), active triangulation (Cerec Bluecam-Sirona), interferometry (DPI-3D-Dimensional photonics International Inc.) or active wavefront sampling (TrueDefinition scanner-LAVA 3M) (27).
As far as data acquisition is concerned, two categories of optical scanners can be distinguished: scanners that acquire data such as still images (e.g. Cerec) and scanners that acquire them by video (e.g. Trios) (Table 1).
Concerning the number of studies on edentulous jaws, we found only 3 *in vitro* and 5 *in vivo* studies studies testing the accuracy of IOS.
One of the first *in vitro* studies was conducted by Patzelt et al. in 2013 and it is considered as reference for the feasibility of scanning edentulous arches (28). Due to the significant development of new software and devices it is interesting to evaluate their new performances in recent studies too (29,30). The 3 *in vitro* studies showed that the digital impression is feasible in edentulous jaws and that only some of the scanners tested are accurate enough to be considered appropriate for clinical use. An alternative way to evaluate accuracy in removable prosthesis is to use the final impression as a reference parameter, considering that the oral environment is very different from the laboratory model (31).
In the literature it is possible to find also *in vivo* studies that evaluated accuracy of digital scanners (32-36), comparing conventional impressions. For example, D'Arienzo et al. (32) compared the preliminary impressions, taken in alginate, with the intra-oral scans obtained by Trios (3 Shape Company) in edentulous maxillary arches, while Hack et al. (36) compared 3 intra-oral scanners (Lava Chairside Oral Scanner, C.O.S. or True Definition Intraoral Scanner) with the functional impressions made of polyvinylsiloxane-based materials after edging the individual impression tray with thermoplastic pastes.
All the authors reported great deviations between the two impression techniques (digital and traditional) in the peripheral areas such as oral vestibule and soft palate.

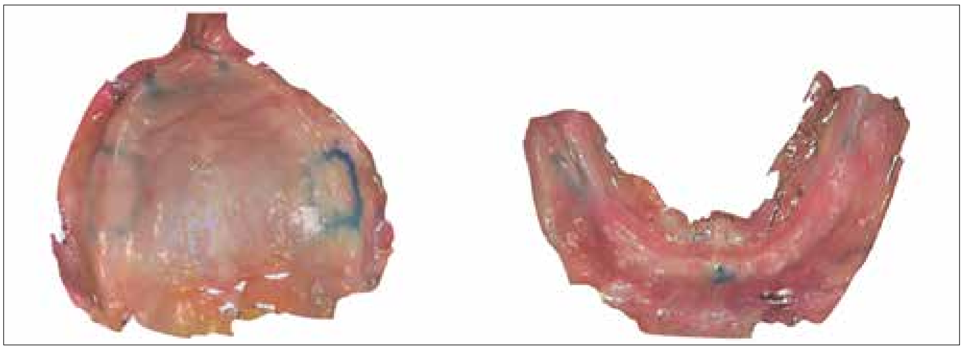

FIG. 2 Optical impressions of edentulous jaws.

It can be assumed that these differences are due to the compressive effect of the impression materials on the resilient tissues. For example Jung et al. pointed out that the soft palate had a much greater difference of 0.86 ± 0.77 mm, and the variations in the other areas were 0.05 ± 0.05 mm (medial palatine raphe), 0.18 ± 0.15 mm (hard palate), and 0.05 ± 0.07 mm (residual ridge) (33).
So according to these articles, both *in vivo* and *in vitro*, digital impression of edentulous jaw is feasible, but there are important limitations in accuracy in peripheral areas (Fig. 2).

Centric registration

To date, there are no digital methods for detecting spatial relationships of jaws, so this step can only pass through a clinical procedure.
The studies that examined the application of digital scanning for inter-occlusal registrations in edentulous patients are provided (37-40), but all of them kept the registration with the traditional method and then scanned the rim which allowed to position the two arches. So it is not feasible to register the centric position in edentulous conditions with a full digital procedure (Fig. 3).

Try-in

Nowadays 3D printing can be used to obtain denture prototypes or final dentures with materials that are not sensitive to temperature (41-44). The product obtained is more accurate and has greater retentive force than a denture base fabricated using heat curing (45), but the CAD-CAM, milled complete dentures are superior to the rapidly prototyped complete dentures in terms of trueness of the intaglio surfaces (42,46).
In regard to the the cost, 3D printing gives the opportunity to test a denture prototype with tooth anatomy in a more economical way (18,47) (Fig. 4).

Finalization of the denture

Several studies investigated the feasibility and the accuracy of this procedure (48-53), as shown in a recent systematic review (53). The purpose of the paper by Wang et al. was to evaluate the accuracy of digital CDs and to summarize the influencing factors, such as type of CAD-CAM systems, manufacturing technique, long-term service, and parameters related to the CAD-CAM process, analytical method and statistical indicators.
According to this review the mean value of the trueness of the intaglio surfaces in the studies analyzed ranged between 0.059 mm and 0.157 mm for milling and between 0.075 mm and 0.143 mm for 3D printing technology. The precision ranged from -0.23 mm to 0.25 mm for milling and 0.090 mm for 3D technology. Moreover the greatest misfit of the intaglio surface of the digital CDs was shown in the posterior palatal seal area and the border seal area, so in that area the anatomical peculiarity (such as undercut) compromised the result of the subtractive technology. As shown by Wang et al. (53), digital CDs showed similar or better denture adaptation than conventionally manufactured ones, ranging between 0.058 mm and 0.29 mm for digital methods and between 0.105 mm and 0.30 mm for conventional technologies. Therefore they underlined that the accuracy of digital CDs is influenced

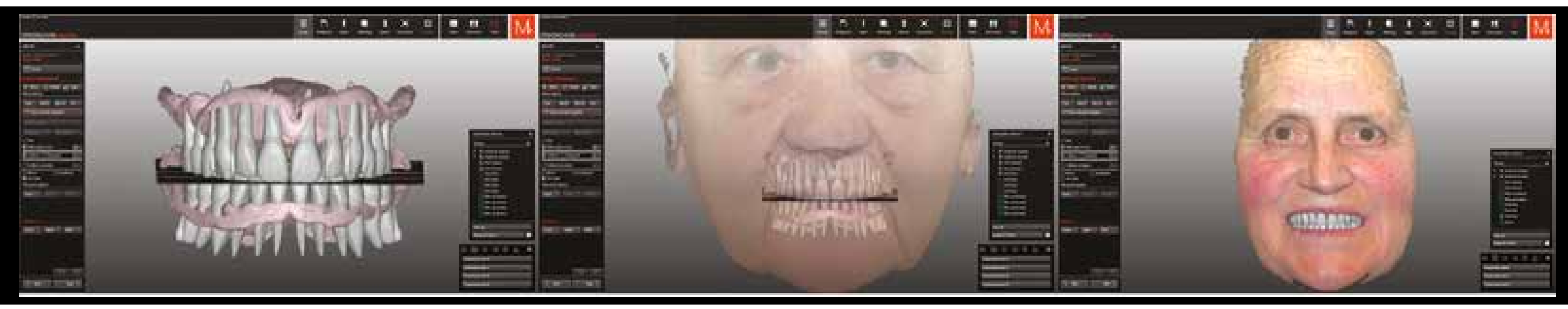

FIG.3 Dentures designed in CAD softwares

FIG. 4 3D printed prototype.

by some factors (such as the manufacturing technique, the different CAD-CAM systems used, and the long-term service) and that no clear conclusions can be drawn about the superiority of CAD-CAM milling and 3D printing regarding denture accuracy. So, the CAD/CAM dentures are feasible and accurate (Fig. 5).

As regards the main factors to analyze in the present review:

- The retention offered by milled complete denture bases was significantly higher than that offered by conventional heat-polymerized dentures (54,55,56). AlHelal et al. used a stainless steel hook attached to denture bases to measure the retention and obtained an average of retention for the milled denture bases group around of 74.14 ±32.56 N, and average of retention for the conventional heat-polymerized denture bases group of 54.23 ±27.36 N (54).
- There was a very high level of patient satisfaction with complete denture constructed with CAD/CAM methods (57,58,59). Saponaro et al., using a questionnaire, revealed that 70% of experienced CD patients agreed that their new digital CDs were "better" than their previous set of CDs (58) (Table 2).

DISCUSSION

The introduction of CAD/CAM technology ushered in a new era in dentistry (60,61). These recent developments were introduced also in the manufacturing of CDs, as reported in several articles (37-40,62), where the dentures are developed with a fully digital protocol, starting from an intra-oral scan.

The available literature focuses mainly on 3-D and linear measurements of impressions or casts of dentate jaws or implanted jaws (63-65). Concerning the studies conducted on edentulous jaws, the published data have been increasing in recent years, but the evidence on accuracy of digital impression is still weak.

In vitro studies dealing with accuracy of IOSs may represent important limitations in case of edentulous jaws. In fact edentulous jaws were covered by oral mucosa that is unstable in several zones (such as in labial vestibule on in the alveolar sulcus), moreover the smooth-surface textures on mucosa is covered entirely by saliva, thus the intra-oral environment cannot be compared with a gypsum or metal model. For this reason in this file the studies conducted *in vivo* are more suitable.

The digital impression of edentulous jaws is described by a certain technical difficulty, thus adequate clinical training is required (39). In the past, the use of intra-oral scanners was not recommended to perform the impression of edentulous jaws due to alleged feasibility and accuracy limits (66). However recently, several *in*

	FEASIBILITY	MAIN OUTCOME(S)
Impression	✔	?
Jaw Registration	✗	
Try in	✔	✔
Delivery	✔	✔

TABLE 2 Feasibility and main outcomes of digital workflow in respect to the traditional one in the clinical aspects observed.

FIG. 5 Milled dentures.

vivo articles (32-36) showed that digital impressions of edentulous jaws are feasible and predictable. On the other hand the same studies showed that optical scanners are not suitable to capture areas of high mobility tissue zone, that are usually emphasized by prosthodontic textbooks as determinant in the retention of complete denture (6,67,68).
The differences between the two types of impressions in those areas are related to two reasons. Firstly the specific software implementations in the scanner delete automatically areas that not steady over time. Current IOS focuses on capturing tissues that remain immobile, thus the software algorithm automatically removes scans of mobile tissue such as the tongue, the vestibule, mobile areas of the palate as well as retractors or similar dental instruments (36). Secondly, when an important part of peripheral sealing zone is impressed, those areas will be different from those registered by the impression materials. This is because the scanner does not determine any pressure to the tissue compared to conventional impression materials. For these reasons, in the studies analysed, with exception for one author (35), the possibility to use only the digital scanner to obtain complete denture is excluded, at least for the moment.
Regarding the centric relation procedures, the present review highlights that nowadays completely digital techniques for determining the spatial relationship of edentulous arches are not described yet. In fact several manufacturers have developed different approaches to obtain complete dentures thanks to digital protocols, but all of them used wax or specific physical devices to detect the centric relation (12).
So, in the present paper, the outcome set in methods was not analyzed. Instead, data regarding to subsequent steps were very encouraging, both for the try-in using the 3D printer and for finalization using milling machines, but it remains questionable how to manage the process when some modifications to the project are required.
Since it is more complex to make changes at this point compared to the traditional technique, the cardinal indication of the printing procedure remains for the edentulous rehabilitation that starts from the copy of the patient's pre-existing denture or teeth (pre-extractive denture) (69).
Regarding the 3D printers, additive production is a manufacturing process that allows to create physical objects starting from a digital model. There are several technologies and materials available, but the basic principle is the same: through the superimposition of layers of material a digital model is transformed into a three-dimensional solid object. It is important to underline that the word "additive production" does not refer to a single technology. Indeed there are several techniques, sharing the following three factors.

1. Production processes used for the creation of three-dimensional objects.
2. Final objects are made by overlapping successive layers of material.
3. Products are developed starting from a digital 3D model.

The 3D printers are generally used to obtain the prototype of the denture, this reports some advantages over subtractive technology. In fact they are generally faster, more reliable and easier to use than other technologies, especially when different undercuts or internal channels are present due to the anatomy (53).
The aims of the denture prototypes are multiple, such as: check the vertical dimension of occlusion; confirmation of the centric relationship; check of the phonetics and aesthetics aspects (6,67,68).
Furthermore the digital approach could be suggested to obtain a prototype that can be worn by the patient for a few hours. Thus evaluating all the aesthetic and functional parameters required for a longer period of time than in the conventional one, thus it can be considered as a valid "test drive" method before finalization. It could be a better method to have the consent from the patient to finalize the denture than the ones used in the conventional approach. It can also guarantee the approval of the family members, that is a parameter that significantly influences the patient satisfaction (70).
The CAM performed by milling is the most widespread system for creating prostheses designed with the CAD technique (20). With this technique, the STL file is sent to a milling software which "translates" it into a series of movements communicated to a milling machine that has a support on which a block of the material chosen for the creation of the prosthetic device is housed.
A recent literature review on CAD/CAM dentures analysed data on computer-engineered complete dentures and tried to determine their advantages over the conventional dentures(20). That paper, as the present one, showed some advantages of digital dentures, such as the reduced clinical chair time and number of visits, electronic archiving of all clinical data from the patient, significantly higher retention, and more favorable clinical and patient-centred outcomes. Furthemore, several studies showed that the absence of polymerization shrinkage associated with milled dentures results in a highly accurate denture fit and improved retention (55,56).
According to the present paper it is clear that, due to some crucial aspects, the impossibility to register the centric position and the reported limits in digital impression, the full digital workflow for the complete denture rehabilitation remains still questionable. However conventional and digital approaches can be combined together in order to reduce the number of clinical visits and increase the patient's acceptance. For example, in the case of a patient with old dentures, it is possible to reduce all the clinical steps in one

appointment, in which the dentist can edge the existing denture obtaining functional impressions and register the centric position starting from the old one. At this point, it could be proposed to use the iOS to collect all data and proceed straight to mill the new denture.
This review reveals that there is still a need to provide data on digital workflow using multiple research methods. So it is important to include both qualitative and quantitative approaches. The first one is used to understand concepts (primarily exploratory research), whereas the second one is used to test or confirm theories that can be transformed into usable statistics. So in qualitative research the sample size is typically smaller than in quantitative studies.

CONCLUSION

The digital revolution is significantly changing dentistry, both in clinical aspects and in laboratory steps in removable prosthodontics. The data available in literature focused mainly on the assessment of the feasibility and accuracy of impressions.
As regards the data relating to the subsequent stages, different types of workflow are very encouraging.
Regarding optical scanning in edentulous arches literature reported some conflicting data because of the impossibility to perform a selective pressure in the areas of the peripheral seal. More concrete evidence was presented in the case of finalization of denture. Instead 3D printers are very interesting, but it remains questionable how to report aesthetic and occlusal changes in the final restoration. The main indication is in case of pre-extractive prosthesis or when the patient's old prosthesis is available.

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