Computer-assisted prosthetic planning and implant design with integrated digital bite registration: a treatment protocol.

F. Cattoni, A. Merlone, R. Broggi, M. Manacorda and R. Vinci

Dental School, Vita-Salute University and Department of Dentistry, IRCCS San Raffaele Hospital, Milan, Italy

The aim of this clinical study is to present an integrated digital project through the description of a clinical case, made entirely in digitized form, taking advantage of the opportunity offered by instrumental diagnostic software. A case report participant is a 65-year-old female patient presents with loss of diffuse bone support, caused by periodontal disease. After a sign of an informed consent and an explication of a plan of treatment, technical intraoral and extraoral pictures and intraoral digital impressions were taken. The digital images improved from the 2D Smile Lynx Software and the scanner stereolithographic (STL) file was matched into the CAD Lynx to obtain a virtual previsualization of teeth and smile design, and to mill the provisional and the definitive crowns. The digital prosthetic design allows the evaluation of the dental parameters in relation to the parameters of the patient’s face for the new prosthetic project and the radiological examination using CBCT guides the insertion of the fixtures for the rehabilitation phase. The surgical and prosthetic design are subsequently integrated. The evaluation of the bone bases is carried out with a radiological diagnostic software for CT (Real Guide 5.0-3Diemme, Cantù-Italy) which can virtually design the implant insertion. The functional examination of the patient is carried out through an occlusion-postural examination that uses digital electromyographic assessments. The integrated digital protocol proposal inserts in the rehabilitation path the digital recording of the free mandibular movement, as well as the scan of the patient’s face, data that will be integrated into the CAD software for the design of temporary and definitive prosthetic artifacts, made using the CAM method. This study showed guided implant placement and the application of fixed implant-supported prosthetic restorations carried out with a fully digital workflow, dependent on the functional digital evaluation of the patient’s occlusion. The proposed protocol described the correct use of digitalization of clinical, surgical, and prosthetic procedures, and the matching of the data into a computerized environment, to improve team communication and to take advantage of the combination of collected data to not lose information using classic manual steps.

The continuous evolution of techniques and new materials in dentistry has made it possible to effectively recreate dental shape and function through a digital protocol that results in a minimally invasive therapeutic approach. Clinicians have been trying for decades to harmonize tooth shapes with the face, based on parameters such as gender, personality, and age, often without achieving desired results (1).

Key words: prosthetic planning and implant, radiological diagnostic software, minimally invasive therapeutic approach

Corresponding author:
Prof. Francesca Cattoni,
Dental School,
Vita-Salute University and Department of Dentistry,
IRCCS San Raffaele Hospital, Milan, Italy
e-mail: cattonif@tiscalinet.it
The introduction by Paolucci et al. of the concept of dental “visagism” in 2012 helped clinicians in the realization of restorations as individualized and personalized as possible (2). Psycho-teeth-facial harmony is the aim that has led to the development of these concepts in recent years (3). At the same time, several Digital Design software has been developed in Dentistry, which have recently developed three-dimensional CAD / CAM design and modelling functions (4).

The “Digital Smile Design” is currently an aesthetic-prosthetic planning tool that can strengthen the diagnostic vision and improve communication by increasing the predictability of the entire rehabilitation treatment. This tool allows an accurate analysis of the individual characteristics of the face and teeth and to transfer the information detected during the objective, photographic and diagnostic evaluation on the model to the 2D software project (5, 6).

By drawing lines relating to the reference skin cephalometry and displaying the modelling using software on intra and extra oral digital photographs with a determined sequence, we can expand the data available during the diagnostic phase, creating a single file available to the specialists of the dental team. (7). In the subsequent interdisciplinary phase of management of the treatment plan, it is therefore possible to evaluate the various therapeutic options, the risk factors due for example to asymmetries, disharmonies, and alterations of aesthetic principles. The aim of Digital Smile Design is consequently to design better, plan better and increase the understanding of the proposed care plans (8).

The digital approach has therefore improved communication in the dental team, between the various specialists and with the dental laboratory: the acquisition of multiple data sets: CBCT, intra and extra-oral scans, virtual aesthetic and implant planning, instrumental study digitized occlusion and masticatory function, can be effectively integrated to optimize a synergistic diagnostic process (9).

The use of implant design programs on CBCT images and the use of surgical templates associated with the digital modelling of the prosthetic component make it possible to perform a monophasic operation that guarantees aesthetics and function in a single surgical time (10-12). In addition, virtual aesthetic planning systems represent a powerful, communicative, and motivational tool for patients, having the potential to actively involve them in the rehabilitation process, also facilitating acceptance and compliance with the treatment plan (6).

**Aim of the study**

The aim of this study is to present an integrated digital project through the description of a clinical case, made entirely in digitized form, taking advantage of the opportunity offered by instrumental diagnostic software. A digital prosthetic design allows the evaluation of the dental parameters in relation to the parameters of the patient’s face for the new prosthetic project and the radiological examination using CBCT, for the guided design of the insertion of the fixtures is necessary for the rehabilitation phase. The surgical and prosthetic design are subsequently integrated.

The functional examination of the patient is carried out through an occlusion-postural examination that uses digital electromyographic assessments.

The integrated digital protocol proposal inserts in the rehabilitation path the digital recording of the free mandibular movement, as well as the scan of the patient’s face, data that will be integrated into the CAD software for the design of temporary and definitive prosthetic artifacts, made using the CAM method.

**Case report (initial situation)**

The 65-year-old female patient presented to the Department of Dentistry of Vita-Salute San Raffaele Hospital in April 2019 and underwent a remote and forthcoming pathological anamnestic evaluation, physical and radiographic examination, and occlusal-postural evaluation. The intraoral radiography of the third sextant and the orthopantomography performed both prior to the sectoral prosthetic load that the patient received in 2018 were evaluated (Fig. 1, 2). Volumetric radiographic evaluation by CBCT of the maxilla was followed for second level investigation and basis for the surgical-prosthetic digital design (Fig. 3).

The patient presents loss of diffuse bone support, caused by periodontal disease. The patient also reported having performed an orthodontic treatment
on the upper and lower arch in adulthood (2003), the residual elements have been joined with composite splinting and metal ligation, the elements of the front group appear vestibular. On physical examination, edentulous areas treated with implant-prosthetic rehabilitation are highlighted. The implant fixtures in positions 15-16 and 46 are well tolerated and presumably osteo-integrated, they do not show pathological probes or mobility. The analysis of the skeletal segment in the third sextant shows an implant failure: recurrent abscesses with pain, edema and chronic peri-implant suppuration led to a short-term failure of the integration of the grafted heterologous material and consequently of the fixtures.

The implant-prosthetic complex has two implants whose very close emergence does not make the prosthesis favorable. The existing rehabilitation excludes the use of the more distal implant as a prosthetic abutment (Fig. 3). From the first level investigations, a severe bone recession is also evident in the element 25 which appears mobile and painful on percussion and with a distal probe greater than 8 mm. An incongruous endodontic treatment associated with an incorrect reconstruction of the abutment, not aligned with the coronal third of the treated canal, is found on element 24.

The reconstructive project envisaged a minimally invasive reconstructive solution with rapid re-functionalization times associated with the removal of elements 24 and 25. The fixtures in zone 26/27 will be removed to ensure tissue healing. The clinical case is dealt with using implant techniques.
the left and a limited opening with significant pain in the right temporomandibular joint. For the reduced translation of the ipsilateral joint, an MRI (nuclear magnetic resonance) was required which showed disc degeneration with non-reversible anterior dislocation (Fig. 9-12). The execution of an articular CT scan was necessary to verify the

that exploit sufficiently large portions of basal bone to integrate stabilized implants with a high torque value and able to support immediate prosthetics (Fig. 4-8).

At the initial functional physical examination, the patient also presents left joint noise and associated pain in opening and closing movements. The gnathological evaluation showed joint creaking on

Fig 6. Initial clinical case, lower arch vestibular view lower arch.

Fig 7. Initial clinical case, superior occlusal view.

Fig 8. Initial clinical case, inferior occlusal view.

Fig 9. RMN TMJ right closed mouth. Normal morphology of the disc condyle.

Fig 10. MRI TMJ left closed mouth. Joint head degeneration with disc dislocation.
degeneration of the joint heads of the TMJ on the left side (Fig. 13, 14).

The initial assessment of muscle activity during maximum voluntary clenching also highlighted a condition of asymmetry with an anterior center of gravity and a reduced inter-arch impact, again resulting from joint pain (Fig. 15).

**Prosthetic-surgical digital project**

The patient is initially subjected to a professional oral hygiene treatment, an implant-prosthetic treatment plan is planned which involves the removal of the implants in the area 26/27, extraction of 24, 25 and 27. At the same time, the placement of two implants with emergence 24 and 26 in guided surgery is hypothesized, of which the distal “tilted” distally to exploit the tuberal bone underlying the maxillary sinus according to the technique of inclined implants.

The evaluation of the bone bases is carried out with a radiological diagnostic software for CT (Real Guide 5.0-3Diemme, Cantù-Italy) which can virtually design the implant insertion, qualitatively assess the degree of bone density of the receiving site and transfer position information for making a surgical guide. It is therefore necessary to
Fig 15. Initial EMG.

Fig 16. Overlay of DICOM images from CBCT to the scan of the patient’s articulated model.
We can therefore associate a project for the construction of the template to the implant design and using the STL data of the dental anatomy to use it as a program for the prosthetic modeling of the provisional with immediate load. In Fig. 16 the working page of the design software is highlighted: through an automatic “matching” function we superimpose the DICOM images of the CBCT on the STL files obtained by scanning the articulated model of the patient (Fig. 16). The implant design phase is carried out on the cross images of the segment concerned. On the element 24 to be extracted, an inter-radicular bone defect can be appreciated, probably due to a fracture of the coronal root third or to periodontal compromise, associated

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**Fig 17. Average bone density.**

**Fig 18. a, b, c. Course of the major palatine artery near the implant site.**
This planning is facilitated by the evidence in the program of the gingival profile obtained by superimposing the model on the DICOM data. Even the average bone density of a jaw that appears little mineralized is calculated automatically by the software that calculates the average bone density in Gray Scale on the surface of the programmed fixture (Fig. 17).

The same procedure occurs for the distal element (element 26) which will occupy the bone at the level of the maxillary tuber, well represented but with very low bone density. Its insertion, foreseeing the post-surgical load, must therefore provide for a minimum reaming of the neo-alveolus, with a sub-preparation that allows the implant to compact the cancellous bone trabeculae during its insertion and increase the insertion torque. A 4.5 mm diameter and 13 mm deep implant is planned (Winsix TTi 4.5/13. BioSafin, Ancona, Italy).

With rhizolysis, the CBCT evaluation confirms the treatment plan that provides for its extraction.

The bone thickness in the vestibular-palatal direction and the absence of the anterior recess of the maxillary sinus allow the programming of a 3.8 X 13 mm implant, also planning the prosthetic connection for prosthesis screwed through an abutment inclined 20 degrees and calculated with a transgingival shoulder height 4. (Winsix TTi 3.8 / 13. BioSafin, Ancona, Italy).

In Fig. 18 (a, b, c) it is highlighted how the computer assisted design for tuberal or tuberal implants with pterygoid anchoring offers an evident surgical advantage, the cross-sectional images clearly highlight the relationships with the adjacent anatomical structures such as the major palatine artery. An assisted intervention in areas of poor...
visibility of the individual anatomy facilitates and optimizes the correct positioning of the implants. The implant planning is completed, and the project is sent to the prosthetist for the verification of the implant connections, the emergence of the abutments and the congruity with the CAD design of the post-operative provisional product.

The intermediate prosthetic connections are also chosen to be positioned during implant surgery: Extreme Abutment Straight for implant in seat 24, and Extreme Abutment angled 20° for implant in seat 26, to balance the angulation of the fixture. The template, made in the laboratory, allows a guided and therefore minimally invasive post-extraction flapless surgery (Fig. 18-20). The intervention in guided surgery, using the dental-supported surgical guide and the immediate prosthetic loading allow rehabilitation in a single step, making the treatment minimally invasive.

**Surgical procedure**

After preparation of the patient, a povidone and chlorhexidine rinses were performed and local anesthesia was administered (13, 14). A flapless surgery was performed, residual teeth and both fixture infected were extracted and the two designed implants were placed respecting the guided surgery protocol, using the surgical guide. The immediate temporary prosthesis was delivered immediately after the surgery without any occlusal contacts (15). After surgery, a Low-level-laser Therapy Protocol with a 645 nm Diode Laser was performed to reduce tissue inflammation and to improve the tissue healing phase (Diode Laser, 645 nm, 0,6 Watt) (EGG Laser, DMT, Lissone, Italy) (16-18). After the post-surgical visit, occlusal balancing changes are made. Six months after the surgery, tissue healing and osseointegration of the implants were achieved, the control recording was made to verify functional adaptation, and the correct loading was made.

**Prosthetic protocol**

The implant project is supported by the design of the prosthesis elements to be used for immediate loading. Two technical photographs of the patient’s face were taken: a first photograph with the patient’s
smiling face and a second intraoral shot of the patient’s face with a mouth opener. (Fig. 21, 22). These photographs are taken by making the patient wear a special calibrator, on which it is possible to identify landmarks.

The two photographs were inserted into the Digital Drawing software (Smile Lynx, 8853 SPA, Pero-MI) and thanks to the calibrator used, the software subsequently processes accurate measurements (Fig. 23). The digital design of the patient’s ideal smile was carried out within the chosen software, based on the study of reference facial lines, using dental libraries contained within the software itself (Fig. 24). Subsequently, impressions were taken with an intraoral scanner (3Di TS, MYRAY, CEFLA sc, Imola-BO-Italy) to obtain fingerprints of the maxillary and mandibular arch in open bite and in occlusal contact (Fig. 25, 26).

A wax was then modeled to record the DVO (Occlusal Vertical Dimension) after the incisors were positioned with respect to normal overjet and overbite values. This wax represents the DVO to be replicated in future prosthetic rehabilitation. The dental arches were then scanned with the wax positioned in the patient’s oral cavity, after having divided it into two symmetrical parts, to ensure the stability of the wax itself. The digital data was sent to the laboratory in STL format. The STL files obtained from the intraoral scan and the 2D digital planning project were sent to the CAD software for 3D modeling (Cad Lynx Evolution- 8853 spa-Pero-MI), and then used first for the CAD design of the prosthetic restoration and subsequently for the CAM realization of the provisional and definitive phase, using the milling technique (Fig. 27, 28).

A scan of the patient’s face was also detected

Fig 23. Digital Smile Project.
using a facial scanner (Face Scan, Bellus 3D, San Diego-California) and inserted as an STL file in the CAD design software, a scan that overlaps the photographic project and the scan. intraoral already integrated within the CAD, as well as the dental project evaluated in the 2D digital design phase (Cad Lynx Evolution- 8853 spa-Pero-MI) (Fig. 29, 30). All the data entered in a single three-dimensional digital file were preparatory to the realization of the patient's final prosthetic project (Fig. 31).

The CAD programming allowed us to create temporarily milled temporaries from 24 to 26 initially for the immediate loading phase, and subsequently, after osseo-integration (6 months after the surgical phase), the temporaries were made and positioned for the upper arch and lower as per digital project, functionalized and a second EMG was performed which showed correct muscle activity in the provisional phase (Fig. 32). Digital diagnostics was also performed to detect free mandibular movement, using a software dedicated to the analysis of the chewing function (ITAKA Cyclops, Itaka Way Med, Kinejaw srl, Venice, Italy). This system is equipped with infrared cameras to detect the face and movements and to it is connected a PC and a software capable of detecting all the mandibular movements according to a commanded sequence (Fig. 33). It was the functional and aesthetic adaptation of the provisional phase, in the presence of good compliance by the patient and in the absence of any pain symptoms, that allowed the final prosthetic finalization, which duplicated the provisional phase, using the integrated digital project. A 3D scan of the
registration of the digital mandibular movements and the initial CAD drawing.

In the final phase, the definitive EMG was performed (Fig. 34) which confirmed a correct distribution of the occlusal contacts, and a final radiographic check with Orthopantomography (Fig. 35).

DISCUSSION

From the clinical and instrumental results obtained we can affirm that the integrated digital design methods are of help both in the initial diagnostic and design phase, and in the surgical and prosthetic clinical phases, as well as functional verification and laboratory CAD design (4). The integration of data
Fig 32. EMG temporary phase.

Fig 33. Free mandibular movement. 3D digital recording.
Fig 34. EMG post-finalization of the prosthetic.

Fig 35. Final orthopantomography.
within a computerized world allows for the reduction of errors and better control of the therapeutic phases, as well as better interdisciplinarity (5).

Achieving an aesthetically pleasing result is one of the most crucial aims of a successful dental prosthetic rehabilitation since the position and number of missing teeth are important factors affecting the quality of life (6, 19). This often requires a multidisciplinary approach consisting of the teamed-up work of different professionals such as prosthodontists, oral surgeons, prosthodontist periodontists, and dental technicians (20).

Thanks to rapid technological advances and materials, it is now easier to achieve an excellent treatment outcome, the satisfied patient. It is also very convenient to visualize the outcome in advance with the aid of rendering software such as Smile Lynx (Smile Lynx, 3D Lynx, 8853 SRL, Varese, Italy). These kinds of software can process different images of patients, helping the clinician to draw guidelines for facial, dental, and gingival analysis, ultimately producing a digital pre-visualization of the result (6, 10, 21).

Surface electromyography was used to determine the impact on the activity of the masticatory muscles, using Teethan device, which consists of four wireless probes placed on the anterior temporal and masseter muscles to detect muscular activity during two clench tasks of 5 second each. This system allows to determine the presence/absence of prevalence, torsions and imbalances through the analyses of the collected data (22-26). Electromyography makes it possible to identify any imperfections in the occlusal load and correct them on the temporary restoration to obtain an adequate and above all tolerated final rehabilitation by the patient (27). Other Authors, on the other hand, have used electromyography to investigate patient satisfaction with implant rehabilitation, obtaining excellent results (28).

Proper occlusion and oral hygiene are critical to the long-term success of dental implants (29). The most recent literature confirms instead the same survival and implant success rate also in patients with systemic diseases (HIV, HCV, SJOGREN), it is also a minimally invasive technique and therefore more suitable in patients with chronic systemic diseases (30-33). Before the surgical and prosthetic treatment, especially in the pandemic actual situation, is however necessary the evaluation of the tissue healing, is necessary to evaluate the inflammatory state of the oral cavity (34-36).

Overloading occlusion can compromise peri-implant health and cause inflammation that can lead to future peri-implant bone loss. Maintaining both the horizontal and vertical dimensions of peri-implant bone is essential to preserve the correct architecture and health of the soft tissues (37). The electromyography examination can be a valid aid in implant-prosthetic rehabilitation to establish the right occlusal load; in fact, some Authors underline how the immediate loading of the implant can influence a high production of the crevicular fluid (38).

Advanced maxillary atrophy is one of the most common clinical scenarios where implant placement could become difficult and volumetric evaluation using suitable diagnostic software could facilitate the implant planning as Manacorda et al. described in 2020, suggesting the potential application of the retro-canine maxillary area as a designated location for virtual tilted implants. (39, 40). A new treatment modality for fixed partial rehabilitation of posterior maxilla with immediate function using 1 anterior axial implant and 1 posterior tilted implant with intra sinus mesial insertion is now described from literature as Agliardi et al. showed in 2014. The results obtained suggest that this approach could allow rehabilitation of the posterior maxilla with immediate function in case of reduced bone volume, representing an alternative technique to bone grafting, short implants, and zygomatic or pterygoid implants (41).

Aparicio et al in 2001 indicated that the use of tilted implants is an effective and safe alternative to maxillary sinus floor augmentation procedures (42). The use of tilted implants to support fixed partial and full-arch prostheses for the rehabilitation of edentulous jaws can be considered a predictable technique, with an excellent prognosis in the short and medium term. (43). Furthermore, immediate loading is nowadays a new concept of implant rehabilitation, to meet the patient's growing expectations in terms of comfort, aesthetics, and shorter treatment period
Immediate loading of dental implants has gained widespread popularity due to its advantages in reducing treatment duration and improving patient aesthetics and acceptance, and compared to early loading, immediate loading could achieve comparable implant survival rates and marginal bone level changes, as Chen J described in 2019 (45). Jan D’haese in 2000 demonstrated how the invention of computerized axial tomography (now known as computerized tomography) and the developments of interactive software to allow virtual planning, with the aim of guiding the surgery precisely toward a specific target, has greatly improved general, as well as oral, surgery.

Virtual dental implant planning enables a prosthetically driven approach, which results in the best prosthesis possible, improved esthetics, optimized occlusion, and loading. This new digital, surgical, and prosthetic approach has also changed the surgical paradigm of using large flaps to obtain a correct view of the surgical area because flapless implant surgery, with or without immediate loading, has become more predictable (46). As Vinci R and Manacorda M. et al demonstrated in 2020, computer-aided surgery is a predictable procedure for implant placement, the study data described that the detected horizontal and angular deviations indicated that flap surgery should be used to prevent implant positioning errors due to poor sensitivity and accuracy in cases of severe jaw atrophy (47). Furthermore, the digital prosthetic procedure is used to minimize the possibility of error and, at the same time, shorten working times. The clinician can rely on effective smile planning tools and CAD/CAM systems, which, as demonstrated by McLaren et Al. (47), have proven their reliability in the realization of adhesive restorations in aesthetic areas. A dedicated digital smile planning software, both two-dimensional-Smile Lynx and three-dimensional-Cad Lynx-3D associated with the use of digital models and CAD / CAM systems for the milling of both the mock-up, the provisional, and the definitive restoration, can obtain excellent results in a simple, standardized and less operator-dependent way (49-53). It should be added that the peculiarity of this study was the simplification of the combination of the dental design carried out on the photographs, according to the facial planes, with the intraoral scans, taking advantage of the integrated three-dimensional dental libraries that allow the automatic alignment, unlike other Authors, like Cattoni et al. described about esthetic dental treatments in 2016 (5).

Finally, this study showed guided implant placement and the application of fixed implant-supported prosthetic restorations carried out with a fully digital workflow, dependent on the functional digital evaluation of the patient’s occlusion. The proposed protocol described the correct use of digitalization of clinical, surgical, and prosthetic procedures, and the matching of the data into a computerized environment, to improve team communication and to take advantage of the combination of collected data to not lose information using classic manual steps.

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REFERENCES


