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Artificial Intelligence And Digital Technologies To Determine The Timing Of Orthopedic Loading Of Implants

Research Article

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Abstract

An innovative technique has been developed for treatment planning and treatment of patients with partial and total loss of teeth using artificial neural networks (ANNs) to optimize and predict the timing of early loading of implants.
Predicting the orthopedic loading at all stages of dental treatment makes it possible to speed up the patient's rehabilitation and shorten the treatment time through a combined intelligent, digital, and automated approach.
The surgical and orthopedic treatment of 89 patients was performed using this technique. The control group consisted of patients with total and partial secondary adentia, who underwent planning and subsequent surgical and orthopedic treatment according to the traditional procedure.
It became possible to accurately predict the loadingofthe implants with a prosthetic restoration and to reduce the period of permanent prosthetics compared to the control group, achieve early osseointegration, and quickly carry out orthopedic rehabilitation of the patient. In most cases, the need for surgery to increase the volume of soft tissue around the implants disappears, which excludes the possibility of causing additional injuries.

Keywords: Artificial Neural Network; Intraoral Scanner; 3D Printer; Torque Load; Primary Implant Stability.

Introduction

The development of implantology gives impetus to a novelapproachto accurate planning and loading prediction at all stages of treatment, as well as to a search for technologies and tools that reduce the time of surgical and orthopedic treatment to quickly rehabilitate the patient.

Interest in immediate or early loading of the implant is currently sharply increasing [1-6]. To achieve high stability parameters of the implant in the bone tissue and reduce osseointegration, modified surgical and orthopedic protocols are used [7-13]:

- subcrestal implant placement;
- implant angulation bypassing important anatomical formations;
- choice of the implant design;
- implant placement in the bone tissue by bicortical technique;
- modifying the working protocol for bone preparation, including its instrumental compaction;
- splinting of provisionalprosthetic restoration on implants;
- placement of a customized provisional composite abutment to form a gingival profile;
- intraoperative installation of a removable platformswitching-base (On1, multiunit).
- plastic surgery of soft tissues immediately after implant placement.

In everyday practice, depending on the primary stability values, it is possible to decide on immediate, early, or delayed loading of the implant. The lack of mechanical mobility of the implant results in changes in the peri-implant tissues leading to a further process of osseointegration and the natural biological framework around the implant, forming, over time, the final secondary stability.

To decide about the loading, the resonance frequency analysis (RFA) for measuring the implant stability, developed by Meredith, is used, based on the measurement of the resonance of electromagnetic waves [14, 15].

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However, this parameter alone is not always enough; it is necessary to take into account the influence of other factors that have a significant effect on the rate of bone regeneration around the implant, for example, the type of prosthetics, the torque force, the type of fixation of thedentalrestoration, the type and class of bone resorption, and the screw-in angle of the implant [16-20].

All of this led us to the idea of combining these parameters into a single patient management scheme based on artificial intelligence, as well as creating a software calculation to determine the timing of orthopedic loading at the surgical phase (Figure 1).

Materials and Methods

After consultation at the planning stage, a number of diagnostic procedures are performed:

- cone-beam computed tomography, which makes it possible to see important anatomical formations around the implantation zone, assess the volume and quality of bone tissue, as well as the type of resorption, perform a preliminary analysis of the position of the implant based on virtual planning, determining its diameter and length, immersion depth and screw-in angle;
- intraoral photo, which allows the patient to evaluate and visualize the clinical picture at a specific point in time;
- portraitphotos,necessary to assess the compliance of the old prosthetic restoration with the anthropometric data of the patient and to discuss the aesthetic requirements for prosthetics of the frontal teeth;
- intraoral scanning of the upper and lower jaws for further digital planning;
- physical examination of the mucosa and determination of the gingival phenotype.

Subsequently, preliminary medical and financial plans are madeand finalized with the patient.

Results and Discussion

Primary Examination Stage

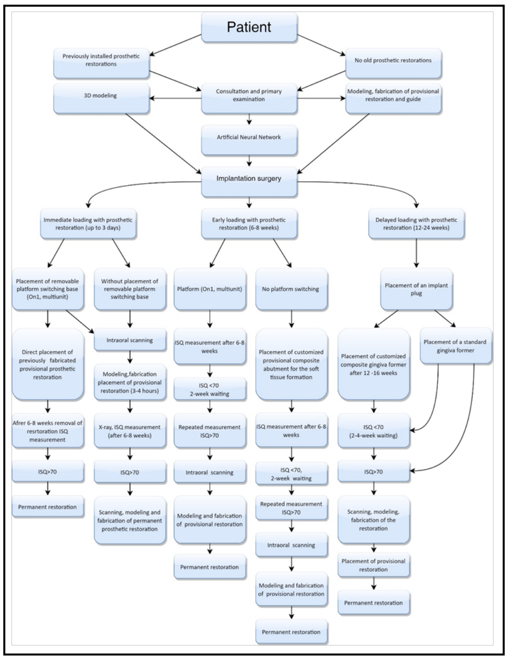
The patient undergoes an X-ray and the anatomy of the alveolar ridge is assessed. Using the software interface and the implant library, the virtual positioning of the implant relative to the bone volume is performed. Next, the type of bone tissue in the area of the proposed installation is determined according to the Hounsfield scale (HU). The units of measurement range from -1024 to +1024. This method is based on the degree of absorption of X-rays by anatomical structures [21].

The consequence of tooth extraction is a decrease in the functional loadingof the alveolar process, which leads to a loss of volume and a change in the structure of bone tissue. Having received a section of the alveolar ridge by CBCT in the proposed implantation zone, the degree of resorption was assessed, which depends on the blood supply to a particular section of the jaw, on the presence oftheprosthesis, the period of missing teeth,as well as on the gender and age of the patient. The Lekchalm and Zarb classification of bone tissue was taken as the basis [22].

Soft tissues provide nutrition to the periosteum and affect the timing of implant integration; therefore, prior to dental implantation surgery, the volume and condition of the mucosa, as well as the need for soft tissue plastics, are assessed [23]. A thin biotype of the gingival tissue is a risk factor for its survival. The optimal predicable result is achieved with a thick type of keratinized mucosa. The gingival biotype was determined according to Rasperini with colored probes (HU-Friedy COLORVUE BIOTYPE PROBE) submerging themone by one into the gingival sulcus and assessed with transmitted light [24].

To create a future prosthetic restoration, it is necessary to obtain a digital image of the teeth, which will make it possible to achieve the ideal accuracy of the provisional restoration and accelerate the patient's rehabilitation. With the help of a special optical sensor

Figure 1. Methodology for predicting the timing of the loading on implants using artificial neural networks and the stages of treatment of patients with partial and total loss of teeth.



mounted in the tip of the scanner, an image is created and automatically converted into an open digital STL format, which allows one to work in any orthopedic modeling program. The process from scanning to imaging takes 30 minutes.

After scanning is completed and the electronic STL file is saved, the Exocad program evaluates and additionally simulates the missing teeth, as well as, if necessary, corrects the shape of the old prosthetic restoration. In the 3 Shape program, in which a computed tomography image is preloaded in the Dicom file format, the virtual placement of the implants and the screwing angle relative tothe image of the future prosthetic restoration are assessed. Having received preliminary information about the type of bone tissue, the class of bone resorption, the biotype of the mucous membrane, the angle of screwing of the implant relative to the alveolar ridge, the type of the planned prosthetic restoration, as well as the torque force to achieve the primary implant stability, we will be able to predict the timing of the prosthetic restoration loading from the moment of the implant placement, using an ANN.

Artificial Neural Network

An artificial neural network was trained to predict the timing of orthopedic loadingof implants using the Statistica Neural Networks software package [25]. For this purpose, clinical observations obtained as a result of surgical treatment with dental implants in 64 patients were used.

Taking into account the results of the primary examination, the selection of the main variables (input parameters) was carried out, which have a significant effect on the rate of bone regeneration around the implant. Input parameters and levels of variation: type of prosthetics (single, bridge), torque force, N/cm2 (from 20 to 45), type of fixation (standard, bicortical), bone type (hard, dense, soft, loose), resorption class (from A to E), screwing angle (straight, angulated). The implant stability coefficient (ISQ)measured by the Penguin RFA device (from 50 to 75 units) directly during the surgery [26] served as an additional factor necessary to correct the timing of the orthopedic loading.

The response function (output parameter) was the duration of the orthopedic loading (in days).

Based on the data obtained, the neural network models were built. An automated neural network with the following settings was chosen as a strategy for building models: network type - multilayer perceptron, minimum and maximum number of hidden neurons - 4 and 12, respectively. The determination coefficient for the training sample is 0.960141. The activation function of hidden neurons is identical and of output neurons is logistic. The squared residuals index ranges from 0 to 6.021, which indicates that the trained neural network can be used to predict the timing of orthopedic loading with high accuracy.

Surgery planning and digital analysis of the orthopedic parameters of the provisional restoration

a) Modelfabrication using 3D printing technology.

Models for the orthopedic treatment planning are fabricated in the Formlab3 apparatus using stereolithography technology, which makes it possible to create a restoration by layer-by-layer solidification of a liquid resin due toexposure to a beam of laser light [27, 28].

The technology makes it possible to quickly and accurately createan image of dentoalveolar models before and after treatment. Once the implant is placed in the desired position, an analog stereographic model is created allowing the specialist to see the final design. If necessary, it is possible to reproduce the original copy using the saved data in the program. Such optimization of the technological process makes it possible to shorten the production time and reduce the cost of consumables in comparison with the traditional method.

The model is used for visualization and assessment of the clinical situation before and after the orthopedic treatment on implants, as well as for the fabrication of a provisional reconstruction prior to surgery.

b) Fabrication of a surgical guide.

Making a guide for implant placement allows one to reduce the risk of complications associated with trauma to important anatomical formations, reduce the time of surgical manipulation, increase the accuracy, and transfer the planned position of the implant, which eliminates unwanted errors in prosthetics compared to the “free drill” method. In the 3Shape design software, the computed tomography data and a digital scan image are merged [29], which makes it possible to determine the inclination of the drilling with a pilot drill and the final position of the implant in the bone. After the guideis modeled, the image is imported into the Formlab program and sent to print.

When modeling the guide, it is necessary to take into account the mobility of the teeth, since in most cases the guide rests on them when it is positioned in the oral cavity. After the surgical guideis made, a metal drill guide template is inserted in it for pilot drilling.Before the surgery, the guide is treated with a 2% solution of Lysoformin-3000 for 15 minutes, then autoclaved for 45 minutes at 120 °C and a pressure of 1.1 atm.

c) Fabrication of aprovisionalrestoration.

If a decision is madeto directly fix the provisional restoration, it is modeled and fabricated prior to the implantation surgery by photopolymer printing in the Formlab apparatus [30]. It is fixed intraoperatively by gluing into the titanium base. In the case of a milled provisional restoration, scanning, modeling, and fabrication are carried out after the implant has been placed.

Implantation Surgery

After treatment of the surgical area with 0.1% chlorhexedine solution, infiltration anesthesia is performed with a solution of ultracaine 1: 100 in an amount of 1.8 ml. A surgical guideistaken from a sterile package and positioned onto adjacent teeth. The windows in the guidemake it possible to determine its exact fit. Using a pilot drill, a flapless tissue preparation is made. Drilling is controlled visually, relative to the metal drill template inserted into the surgicalguide. The surgical guideis removed and an X-ray of the position of the guide pin in the bone tissue is taken to control the position of the implant relative to the roots of adjacent teeth.

The final preparation is carried out in the "free drill" position. The implant is placed under the control of a special positioner that controls the position of the implant platform and the immersion depth.

After the implant placement, using a torque wrench, the force with which the implant was installed in the bone tissue is finally measured, and the implant stability quotient (ISQ) is determined using a special device.

The ISQ index directly depends on the compressibility and the level of integration of the implant, as well as the bone quality. The inserted Mul Tipeg pin, by a noncontact method, transmits impulse vibrations depending on the density of the contact between the implant and the bone, and the values are output to the device after 1-2 seconds.

The values of the torque force and the ISQ are entered in the ANN program for the final verification of all parameters and making a decision on the timing of the orthopedic loading. After receiving the data within 5 minutes, a decision is made on immediate, early, or delayed loading with the restoration.

Immediate Loading

In the case of immediate loading, including one-stage implantation immediately after tooth extraction, to correct the inclination angle of the implant, a decision is made to install a removable platform switching base - multiunit, On1 (Figure 2).

After placing the implant in the required position, the platform switching (On1) base is installedusing a special holder. The height of the platform switching and the passiveness of the installation of the base in the implant relative to the bone and soft tissues must be controlled. To control the exact position of the base in the implant, X-ray control is performed (Figure 3).

On the base, a torque force of 30 N/cm^2 is applied to the screw. The system with a changing inclination angle, multi unit, is used for bridge-like restorations, including extended ones. For ease of insertion into the implant, the multiunit system is provided with a plastic holder and an additional screw for changing the inclination angle of the titanium platform. The base has an internal thread for attaching prosthetic components. Multiunit straight and angled systems (17 and 30 degrees of inclination) are manufactured by various companies. The base height varies from 2.0 to 5.0 mm. The systems are supplied by the manufacturer in sterile packaging.

After placing the implants in the correct orthopedic position, the implant shaft is irrigated and a certain height and multiunit angle are set. After installation, the fit of the base into the implant is controlled radiographically. The base should not exert pressure on the alveolar bone. The torque force of 30 N/cm^2 and 15 N/cm^2 on straight and angled multiunit abutments, respectively,is set with a special wrench (Figure 4).

The installation of such a system into the implant and the absence of compression in this area of the bone lead to bone growth to the height of the titanium base and allow one to place the future restoration in the correct orthopedic position, as well as to achieve accuracy when placing its frame.

If the orthopedic loading is immediate, then a scan marker is installed on the platformswitchingbase (On1/multiunit) and intraoral scanning is performed. Using the generated STL file, the provisionalrestorationis modeled in the Exocad program and

Figure 2. Insertion of the ON 1(NOBEL) system into the implant:
a) bone reduction around the implant;
b) installment of a removable platform switching base.

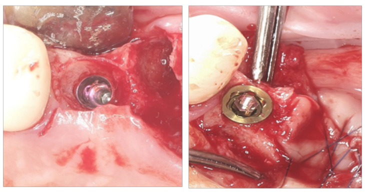


Figure 3. Radiographic control of placing the base into the implant during the surgery.

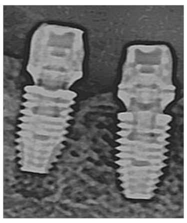


Figure 4. Placement of the implant (a) and multiunit into the implant (b).

then it is fabricated. The entire stage from scanning to placement takes 3-4 hours.

The provisionalrestorationis installed with a torque force up to 25 N/cm^2.

After 6 - 8 weeks from the moment of installation of the provisionalrestoration, it is removed and the X-ray control of the implant integration, as well as the repeated measurement of the ISQ are performed. The index, as a rule, varies from 70 to 80 units, which indicates the possibility of prosthetics with a permanent prosthetic restoration.

When the final integration of the implant is achieved and the provisional crown has formed a gingival profile, the restoration is removed and the scan marker is placed. The image in the form of an STL file is fixed in a special programandmerged with the image of the provisionalrestoration, which was simulated earlier. A permanent orthopedic product is made of a biocompatible material and installed in an implant with a torque force of 30-35 N/cm^2.

Early Loading

After obtaining the results for early loading with the restoration, a customized provisional composite abutment is placed intraoperatively to allow for soft tissue formation during the period of implant integration.

The technology allows for soft tissue formation both from the level of the implant immediately after its placement and from the level of the removable platform switching base (multiunit, On1).

The customized composite abutment is fabricated using the Cervicosystem, which allows one to select the shape for the future gingival profile and set the depth of implant immersion into the bone of 0-4 mm.

After the final setting in the Cervico system of the necessary parameters for the fabrication of a customizedprovisional abutment, an analogue of the corresponding implantation system is fixed in the device. The diameter of the analogue completely coincides with the dental implant, which will be installed in the bone tissue. The provisional abutment in the analogueis fixed with a screw, followed by filling the corresponding guide cell with a flowablelight composite and polymerization.

After the composite has hardened, the abutment is removed from the device, the occlusal position is assessed using the planning models and shortened relative to the antagonist teeth.

A customized composite provisional abutment is fabricated prior to surgery, treated with a 2% solution of Lysoformin-3000 for 15 minutes, and then autoclaved for 45 minutes at 120°C and a pressure of 1.1 atm. (Figure 5). Provisional suprastructure for the formation of soft tissues is installed in the implant with a torque force on the screw up to 15 N/cm^2.

The accuracy of the position of the constructionis controlled using an X-ray image. The opening of the provisional abutment shaft is closed with a light composite. After installation, sutures are applied to hold the flap, and additional soft tissue plastic surgery is performed.

After determining the timing of the early loading with the prosthetic restoration, radiographic control of the implant integration is performed, the customized composite abutment is removed, and the ISQ is measured. If the ISQ is less than 70 points, one should wait 2 weeks more and repeat the assessment of the implant stability. If the index is more than 70 points, one can proceed to the stage of provisional prosthetics using the digital impression method, and after 2 weeks of adaption of the provisional restoration, start milling the final restoration, the fabrication steps of which were described earlier.

Delayed loading

If during the surgery the final prognosis isdelayed loading with the prosthetic restoration, the implant plug is placed, and the mucoperiostealflap is completely sutured. The implant must be completely submerged under the soft tissue and at rest with no load.

Figure 5. Soft tissue formation with a customized composite abutment at early loading:
a) gingival profile after 6 weeks;
b) customizedc omposite abutment.

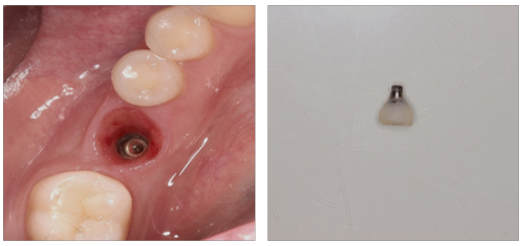


Figure 6. Partial secondary adentia (extended bridge-like prosthetic restoration in the upper jaw was installed more than 10 years ago).

During waiting for integration, the radiographic control of the implant behavior in the bone tissue is carried out after 6, 12, and 20 weeks. After the expiration of the waiting period, the implant is opened, the plug is removed, and the ISQ is measured. If the index is more than 70 points, one can start the loading and proceed to prosthetics with a prosthetic restoration. The patient is fitted with a customized provisional composite abutment, and soft tissue plastic surgery is performed.

In 2-3 weeks after the soft tissue formation, it is possible to fabricate the final restoration.

Clinical case

Female patient Svetlana D., 64 years old, complained of the mobility of the bridge-like prosthetic restorationin the upper jaw. The diagnosis (K08.1) was made: partial secondary adentia, loss of teeth due to an accident, extraction, or local periodontal disease (Figure 6).

A plain CBCT was performed, the prosthetic restoration was removed, and the mobility of teeth 15.12.21.22 of Grade II was established (Figure 7).

The type and resorption of bone tissue in the implantation area was determined. The timing of the orthopedic loading of the implants was calculated with the help of the ANN as immediate.

For provisional rehabilitation in the preoperative period, provisional composite crowns were made (Figure 8).

A decision was made to extract teeth under the old prosthetic restoration with one-stage installation of dental implants in positions 16.14.13.11.21.23.24. A prognosis was made for immediate loading with an immobilizing provisional conditionally removable prosthetic restorationon the day of surgery. The positions of the implants, the type of fixation, and the angle of their placement relative to the alveolar ridge were determined.

Intraoral scanning of the image of the old prosthetic restoration, as well as the abutment teeth was performed (Figure9).

A DICOM file of conebeam computed tomography is uploaded to the program for planning the position of implants in the bone tissue, relative to the image of the future prosthetic restoration (Figure 10).

The final simulation of the provisional crowns on the implants was performed, taking into account the image of the patient's old restoration. A virtual merging of images was performed, as well as a simulation of the surgical guide (Figure 11 – a-d).

In a few hours, a provisionalprostheticrestorationisfabricatedusing a milling machine (Figure 12) and a surgical guideusing a 3D printer (Figure 13).

Atraumatic extraction of teeth 11.22.was performed, a surgical guide was placed on teeth 15.25., pilot drilling and control of the orthopedic position of the implants relative to the future restoration were carried out.

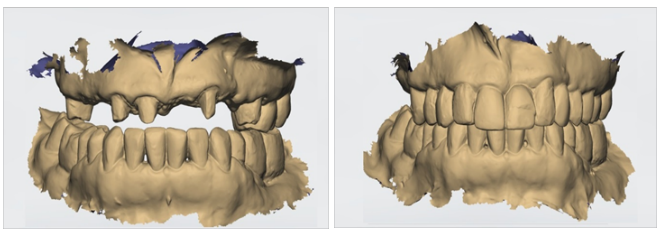
The implants were installed in positions 16.14.13.11.21.23.24. (Figure 14).

Using the ANN, the timing of orthopedic loading was finally de-

Figure 7. Overloading of the upper jaw teeth under the bridge-like restoration.

Figure 8. Provisional crowns for rehabilitation prior to implantation.

Figure 9. STL files after scanning.



termined, based on the data of the primary implant stability and the value of the ISQ at the time of implant placement (Figure 15).

Removable platform switching bases (multiunit) were installed for leveling the inclination angle of implants with a conical connection and for obtaining the effect of passivity when fitting the prosthetic restoration. The latter was placed on natural teeth 15.25. to determine the correct position of the crowns on the implants in the oral cavity. Asilicone imprint from the multi-units served as a fit checker. After a precise position was determined, the restoration was glued directly onto provisional abutments in the oral cavity with adual-polymerization composite (Figure 16).

The final check of the implant stability will be performed 8 weeks after the start of the surgery and, in the case of complete implant integration, will be replaced with a permanent restoration.

Conclusions

The application of the developed innovative methodology for treatment planning and treatment of patients with partial and total loss of teeth using elements of artificial intelligence provides a way to determine the duration of the patient's orthopedic rehabilitation with high accuracy on the day of surgery, which makes it possible to accelerate the process of rehabilitation and reduce the treatment time by a combination of digital and automated approach.

References

[1]. Zembić A, Glauser R, Khraisat A, Hämmerle CH. Immediate vs. early loading of dental implants: 3-year results of a randomized controlled clinical trial. Clin. Oral Implants Res. 2010 May;21(5):481-9.
[2]. Pigozzo MN, da Costa TR, Sesma N, Laganá DC. Immediate versus early loading of single dental implants: A systematic review and meta-analysis. J Prosthet Dent. 2018 Jul 1;120(1):25-34.
[3]. Xu L, Wang X, Zhang Q, Yang W, Zhu W, Zhao K. Immediate versus early loading of flapless placed dental implants: a systematic review. J Prosthet Dent. 2014 Oct;112(4):760-9.Pubmed PMID: 24831750.
[4]. Chen J, Cai M, Yang J, Aldhohrah T, Wang Y. Immediate versus early or

Figure 10. Planning the position of the implants relative to the anatomy of the alveolar ridge and prosthetic restoration.

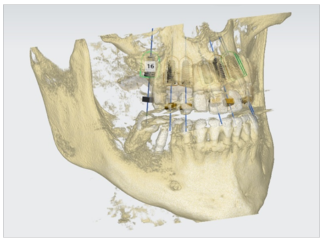
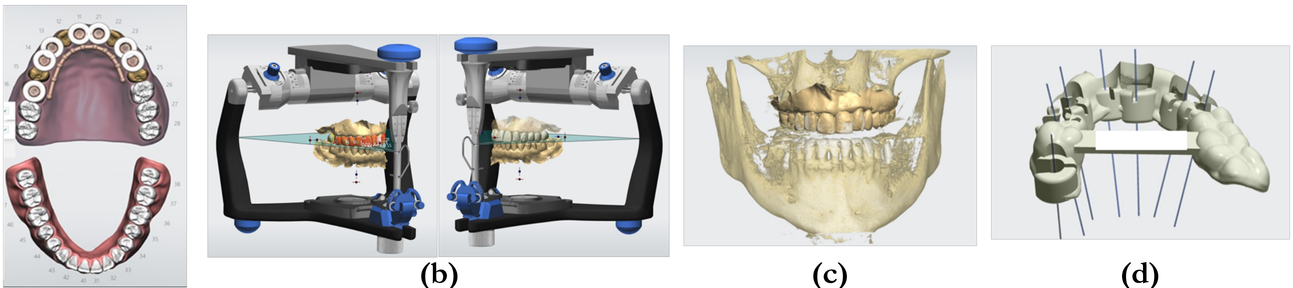


Figure 11. Final simulation:
a) surgicalguide with respect to a new image of the prosthetic restoration;
b) images of the restoration on implants in a virtual articulator;
c) merging of the old and new images of the prosthetic restoration in the 3shape program;
d) image of a surgical guide.



(a) **(b)** **(c)** **(d)**

Figure 12. Finished provisional restoration.

Figure 13. Fabricated surgical guide.

Figure 14. Radiographic control of the placement of removable platform switching bases (multiunit).

Figure 15. Primary stability test with a torque wrench (a) and determination of the implant stability quotient using the Penguin device (b).

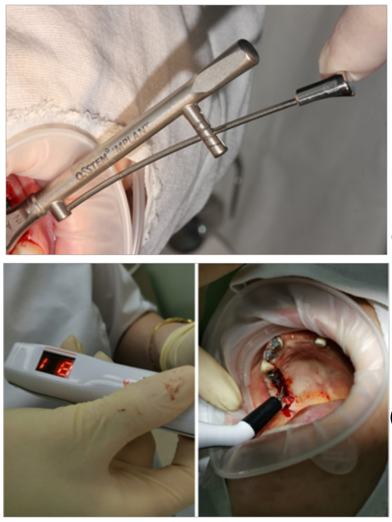


Figure 16. Placement of the prosthetic restoration on the day of surgery.

conventional loading dental implants with fixed prostheses: A systematic review and meta-analysis of randomized controlled clinical trials. J Prosthet Dent. 2019 Dec 1;122(6):516-36.

[5]. Yamamoto M, Ogawa T, Yokoyama M, Koyama S, Sasaki K. Influence of immediate and early loading on bone metabolic activity around dental implants in rat tibiae. Clin Oral Implants Res. 2014 Sep;25(9):1084-90.Pubmed PMID: 23802506.

[6]. Maryod WH, Ali SM, Shawky AF. Immediate versus early loading of mini-implants supporting mandibular overdentures: a preliminary 3-year clinical outcome report. Int J Prosthodont. 2014 Nov-Dec;27(6):553-60.Pubmed PMID: 25390870.

[7]. Pellicer-Chover H, Peñarrocha-Diago M, Peñarrocha-Oltra D, Gomar-Vercher S, Agustín-Panadero R, Peñarrocha-Diago M. Impact of crestal and subcrestal implant placement in peri-implant bone: A prospective comparative study. Med Oral Patol Oral Cir Bucal. 2016 Jan 1;21(1):e103-10.Pubmed PMID: 26615504.

[8]. Ramaglia L, Toti P, Sbordone C, Guidetti F, Martuscelli R, Sbordone L. Implant angulation: 2-year retrospective analysis on the influence of dental implant angle insertion on marginal bone resorption in maxillary and mandibular osseous onlay grafts. Clin Oral Investig. 2015 May;19(4):769-79. Pubmed PMID: 24998769.

[9]. Rasouli R , Barhoum A , Uludag H . A review of nanostructured surfaces and materials for dental implants: surface coating, patterning and functionalization for improved performance. Biomater Sci. 2018 May 29;6(6):1312-1338.Pubmed PMID: 29744496.

[10]. Verri FR, Cruz RS, Lemos CA, de Souza Batista VE, Almeida DA, Verri AC, et al. Influence of bicortical techniques in internal connection placed in premaxillary area by 3D finite element analysis. Comput Methods Biomech Biomed Engin. 2017 Feb;20(2):193-200.Pubmed PMID: 27409042.

[11]. Akin R. A New Concept in Maintaining the Emergence Profile in Immediate Posterior Implant Placement: The Anatomic Harmony Abutment. J Oral Maxillofac Surg. 2016 Dec;74(12):2385-2392.Pubmed PMID: 27475245.

[12]. Cardaropoli D, Gaveglio L, Gherlone E, Cardaropoli G. Soft tissue contour changes at immediate implants: a randomized controlled clinical study. Int J Periodontics Restorative Dent. 2014 Sep 1;34(5):631-7.

[13]. Slagter KW, den Hartog L, Bakker NA, Vissink A, Meijer HJ, Raghoebar GM. Immediate placement of dental implants in the esthetic zone: a systematic review and pooled analysis. J Periodontol. 2014 Jul;85(7):e241-50. Pubmed PMID: 24502614.

[14]. Kästel I, de Quincey G, Neugebauer J, Sader R, Gehrke P. Does the manual insertion torque of smartpegs affect the outcome of implant stability quotients (ISQ) during resonance frequency analysis (RFA)? Int J Implant Dent. 2019 Dec 12;5(1):42.Pubmed PMID: 31828457.

[15]. Becker W, Hujoel P, Becker BE. Resonance frequency analysis: Comparing two clinical instruments. Clin Implant Dent Relat Res. 2018 Jun;20(3):308-12.

[16]. Budak I, Kosec B, Sokovic M. Application of contemporary engineering techniques and technologies in the field of dental prosthetics. J. Achiev. Mater. Manuf. Eng. 2012 Oct;54(2):233-41.

[17]. Oliscovicz NF, Shimano AC, Marcantonio Junior É, Lepri CP, Dos Reis AC. Analysis of primary stability of dental implants inserted in different substrates using the pullout test and insertion torque. Int. J. Dent. 2013 Jan 1;2013:194987.

[18]. Shibata Y, Tanimoto Y. A review of improved fixation methods for dental implants. Part I: Surface optimization for rapid osseointegration. J Prosthodont Res. 2015 Jan;59(1):20-33.Pubmed PMID: 25530606.

[19]. Park YS, Lee SP, Han CH, Kwon JH, Jung YC. The microtomographic evaluation of marginal bone resorption of immediately loaded scalloped design implant with various microthread configurations in canine mandible: pilot study. J Oral Implantol. 2010;36(5):357-62.Pubmed PMID: 20545528.

[20]. Michalakis KX, Calvani P, Muftu S, Pissiotis A, Hirayama H. The effect of different implant-abutment connections on screw joint stability. J Oral Implantol. 2014 Apr;40(2):146-52.

[21]. Shokri A, Ramezani L, Bidgoli M, Akbarzadeh M, Ghazikhanlu-Sani K,

Fallahi-Sichani H. Effect of field-of-view size on gray values derived from cone-beam computed tomography compared with the Hounsfield unit values from multidetector computed tomography scans. Imaging Sci Dent. 2018 Mar;48(1):31-39.Pubmed PMID: 29581947.
[22]. Al-Ekrish AA, Widmann G, Alfadda SA. Revised, Computed Tomography-Based Lekholm and Zarb Jawbone Quality Classification. Int J Prosthodont. 2018 Jul/Aug;31(4):342-345.Pubmed PMID: 29953564.
[23]. Hämmerle CH, Tarnow D. The etiology of hard-and soft-tissue deficiencies at dental implants: A narrative review. J. Clin. Periodontol. 2018 Jun;45:S267-77.
[24]. Rasperini G, Acunzo R, Cannalire P, Farronato G. Influence of Periodontal Biotype on Root Surface Exposure During Orthodontic Treatment: A Preliminary Study. Int J Periodontics Restorative Dent. 2015 Sep-Oct;35(5):665-75.Pubmed PMID: 26357696.
[25]. Grigor'ev VA, Kalabukhov DS, Rad'ko VM. Application of neural network approximation methods in the generalization and presentation of the aircraft gas turbine engine turbomachinery characteristics. Russ. Aeronaut (Iz VUZ). 2015 Jan;58(1):48-53.
[26]. Herrero-Climent M, Santos-García R, Jaramillo-Santos R, Romero-Ruiz MM, Fernández-Palacin A, Lázaro-Calvo P, et al. Assessment of Osstell ISQ's reliability for implant stability measurement: a cross-sectional clinical study. Med Oral Patol Oral Cir Bucal. 2013 Nov 1;18(6):e877-82.Pubmed PMID: 24121909.
[27]. Alharbi N, Osman RB, Wismeijer D. Factors Influencing the Dimensional Accuracy of 3D-Printed Full-Coverage Dental Restorations Using Stereolithography Technology. Int J Prosthodont. 2016 Sep-Oct;29(5):503-10. Pubmed PMID: 27611757.
[28]. Hada T, Kanazawa M, Iwaki M, Arakida T, Minakuchi S. Effect of printing direction on stress distortion of three-dimensional printed dentures using stereolithography technology. J Mech Behav Biomed Mater. 2020 Oct;110:103949.Pubmed PMID: 32957241.
[29]. Lemos LS, Rebello IM, Vogel CJ, Barbosa MC. Reliability of measurements made on scanned cast models using the 3Shape R700 scanner. Dentomaxillofac Radiol. 2015 Jun;44(6):20140337.
[30]. Xu X, Awad A, Robles-Martinez P, Gaisford S, Goyanes A, Basit AW. Vat photopolymerization 3D printing for advanced drug delivery and medical device applications. J Control Release. 2021 Jan 10;329:743-757.Pubmed PMID: 33031881.