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The digitisation for the immediate dental implantation of incisors with immediate individual prosthetic restoration

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ABSTRACT

Purpose: The purpose of this study is to present the author's method of planning the procedure of immediate implant-prosthetic restoration in place of a tooth qualified for removal by performing a surgical template and implant-prosthetic restoration based on data obtained in the CBCT test and intraoral scanning 3D model.

Design/methodology/approach: The method of planning the implant surgery through the design and manufacture of surgical templates and implant prostheses performed before the start of medical procedures was described on the basis of actual clinical data from patients with anterior segment teeth qualified for extraction for reasons of complications after endodontic treatment. The placement of the implant was planned using virtual reality, where the bone model and the virtual soft tissue model were combined, which made it possible to perform a surgical template and prosthetic implant restoration. For the manufacturing, 3D printing as stereolithography SLA and selective laser sintering SLS for the surgical template manufacturing and CNC milling in the case of the prosthetic implant were used for restoration.

Findings: The method allows planning the implant position based on two connected bone and soft tissue models and allows to design and manufacture a surgical guide. In this way, it becomes possible to place implants in the patient's bone during surgery procedure in the planned position and to install the prosthetic implant restoration in the form of an individual abutment and a PMMA crown during the same procedure in the surgical part.

Practical implications: Thanks to the method of computer-aided design/manufacturing CAD/CAM production of surgical templates and prosthetic restoration based only on digital models and the planned position of the implant, it is possible to carry out the procedure of immediate tooth extraction and replacement with permanent prosthetic restoration. The whole process is based on the CBCT test performed at the beginning. The presented method allows shortening the procedure time by four times and the rehabilitation time by 3-6 months when performing the procedure in a minimally invasive manner.

Originality/value: This article presents the original design and production method of surgical guides. It allows for precise planning of the implant position and transfer of this data to the patient's mouth during the procedure, enabling permanent prosthetic restoration before starting medical procedures.

Keywords: Surgical guides, Immediate implant prosthetic restoration, Individual abutments, Dental implants, 3D printing, CNC milling, Computed tomography with cone beam

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BIOMEDICAL AND DENTAL ENGINEERING AND MATERIALS

1. Introduction

For nearly two and a half centuries World is actively involved in the dynamic development of the industry due to continuously and systematically taking place the industrial revolution, which now reached the stage of Industry 4.0. This process is associated with the full computerisation and automation, exchange of information with the use of cloud computing, the use of artificial intelligence tools and product design using computer-aided methods of CAD/CAM manufacturing. The authors' own works [1-6] indicates the assumptions of the augmented holistic Industry 4.0 model. This model takes into account the importance of not only the cyber-physical system but also the importance of material design and application of appropriate engineering materials, appropriate development and selection of technology for the manufacturing of products and their elements, as well as appropriate selection of equipment, machines and technological base. It turns out, desired that this development takes place not only in large industrial organisations, among others, in the automotive, aviation, defence and electronics industries, but also small manufacturing organisations dealing with small-lot or even unique production. The issue mainly concerns the dental engineering what became the basis for the development of the digitisation concept within the framework of the model of Dentistry 4.0, which is also justified in works [1,7]. Inevitable thus becomes a widespread application of this model, mainly due to the behaviour of very high-quality standards and tight tolerances. When treating a patient, a dentist may also benefit from this advanced stage of technological development, but this requires him/her to work closely and closely with a dental engineer. Appropriate design of materials and technological restorations, including dental implants, play a significant role with regard as well as the using of biomaterials and manufacturing technologies. It forces the application by the dentist advanced methods of diagnosing the state of the patient's teeth. Digital technology application allows a reduction in manufacturing cost of some dental restorations as compared to conventional methods. It gives the possibility of creation and implementation of the individual dental restorations during a single visit to the dentist, after diagnosing and imaging condition of bone tissues and teeth of the patient [8,9]. Of course, it is the basis for the design and production of the entire prosthetic restoration by the dental engineer before this only visit to the dental clinic. Model Dentistry 4.0 also enables broader integration of the network of providers and patients, which fully corresponds to the dental version of the smart factory. Although the issue concerns strictly technical aspects related to the manufacturing of dental restorations it has a direct impact on the quality of medical services and the level of dental treatment, and thus the health of the patient, aesthetic impressions related to dental prosthetics and the level of patient satisfaction. It is therefore directly related to the increase in the overall level of health care and broad and complementary field of using of materials and technologies of computer-aided design/manufacturing CAD/CAM concerning any dental restorations, including dental implants [10]. The stereolithography SLA is used concerning models and surgical guides, the technology of milling using computerized numerical controlled CNC machines as hybrid or competing, as well as the application in justified cases atomic layers deposition ALD. The relevant machinery and equipment and highly specialized software CAD/CAM is applied using computer networks, cloud computing, metadata, augmented reality and artificial intelligence tools. The dissemination of such a modern approach in dental prosthetics is a command of the moment and a specific direction of development. However, this requires systematic adaptation of the above assumptions to individual clinical cases, and the clinical and technological experience accumulated in this way enables real progress to be felt directly by patients. One possible clinical case is considered in this article used the digital approach to the design and manufacturing of the needed dental restorations for this patient.

2. The scope of the clinical problem

The clinical situation related in particular to the need to remove the incisors for various medical indications such as tooth root fracture or rupture or irreversible changes after root canal treatment, without the possibility of repeated treatment is one of the most challenging situations in modern dental implantology. If a bone lamina does not surround the tooth from the vestibule side, its removal causes a permanent loss of the volume of the bone from the vestibule side on the alveolar ridge, a change in the shape of the alveolar ridge, i.e. bone atrophy, which also causes atrophy and deformation of soft tissues. With a traditional approach, it is necessary to remove the tooth and replace it with a temporary restoration, e.g. with an adhesive bridge, the waiting 8-10 weeks for the alveolar ridge to heal, implantation in place of the lost tooth, and then after waiting for minimum 3 months of implant prosthetic restoration [11-13]. In extreme cases, this results in a significant loss of volume of the alveolar ridge areas planned implantation. Therefore the only possibility to perform implantation becomes implantation much deeper below the tops of adjacent teeth which disrupts the ratio of the height of the implant to the hight of restoration prostheses, resulting in a reduction time to maintain the implant in the long term and is an undesirable situation [14]. Bone atrophy is resulting in deformation of soft tissues, which consequently extends the longeth of the clinical crown of the planned implant prosthetic restoration. It significantly reduces the aesthetics of the entire restoration and reduces its functionality. In extreme situations, after tooth extraction, the disappearance and deformation of the outer bone lamina of the alveolar ridge make implantation impossible due to the too narrow bone protrusion preventing implant placement [15].

The bone base is necessary to maintain at a level similar occurring with the removed tooth to prevent this type of situation. For this purpose, it is necessary to immediately replace the tooth with an implant along with the implant prosthetic restoration in the form of an individual abutment and temporary crown, which for clinical reasons should be excluded from the bite for the time of implant healing, and then replace it after a period of 3-6 months. It is possible to try to perform such a procedure without intraoperative navigation by inserting the implant into the alveolus after the tooth has been removed and ensuring its primary maintenance, then selecting a standard abutment. Then a temporary crown is made on this abutment from the materials used in the dental clinic. Such treatments are described in the literature [16-19]. Matching the finished elements together with the crown made by the dentist during the procedure, is very time-consuming. Such a procedure can last about 2-2.5 hours. Aesthetic effects are difficult to predict and, in technical terms, the prosthetic restoration is incorrect in most cases. In the case of implants embedded below the line of the tips of the adjacent teeth, the standard abutments do not have such high subgingival zones, which means the crown is located much below the gum line irritating the tissues and causing them to disappear up to the margin of the installed abutment.

Modern dental engineering makes it possible to plan such a procedure before tooth extraction. It is necessary to carry out a study using cone-beam computed tomography (CBCT), planning treatment and realization precision implant surgical guide which allow of accurately transfer the planned position of the implant to the mouth of a patient so as to allow the fitting of individual, where installing is temporary prosthetic restoration [20,21]. For such a plan to be implemented, it is necessary to use the latest technology available in dental engineering [22]. First of all, the dentist must investigate the situation in the patient's mouth using cone-beam computed tomography (CBCT) (Fig. 1) for creating a bone base model (Fig. 2). Then it is necessary to make a surgical guide using SLA 3D printing technology [23,24]. Next, using a CNC milling machine, an individual titanium abutment is made with a temporary crown made of poly(methyl methacrylate) PMMA.

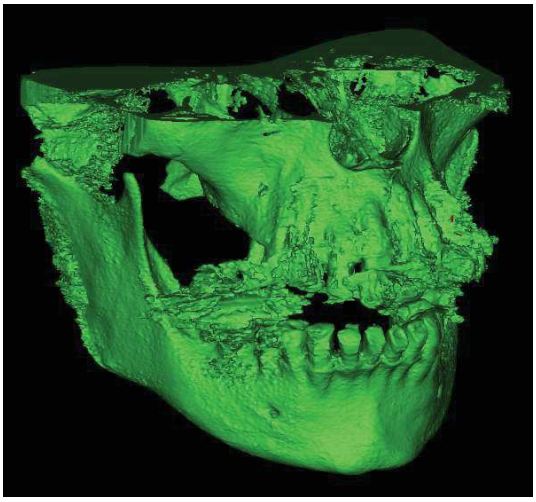


Fig. 1. View of the tomogram constituting the basis for the virtual 3D model of the bone base

The implementation of the treatment plan using the digital method described in this article allows for the implementation of a prosthetic restoration that will optimally fill the alveolus, ensuring first the primary

stabilisation of the implant, correct placement of the individual connector margin and a highly esthetic temporary crown. From a technical point of view, nothing stands in the way, to perform the final restoration, however, from a clinical point of view, temporary crown is the solution to guarantee better maintenance of the implant without exposing it to excessive force bite in the initial period immediately after implantation, significantly increasing the chances of successful implantation immediate. The condition for the success of the entire treatment plan is atraumatic tooth extraction, ensuring the preservation of the bone base around the removed tooth, which is not the subject of this study.

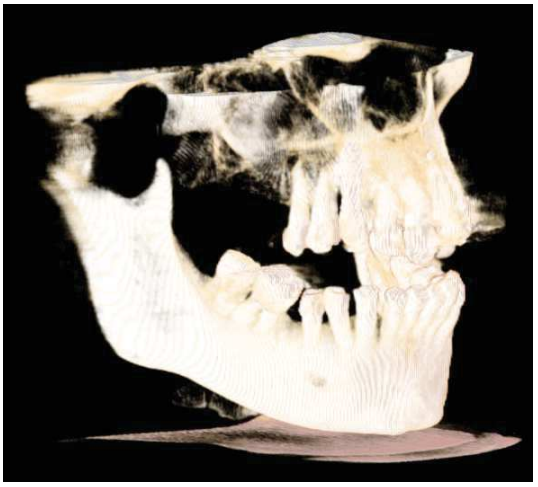


Fig. 2. View of the virtual 3D model of the whole oral bone

The purpose of this article is to present an approach consistent with the assumptions of the Dentistry 4.0 model and methods of computer-aided design and production of immediate implant prosthetic restoration on a specific clinical example.

3. The extent of the study and description of the selected clinical case

This article describes the methodology of conduct related to the design, manufacture and application in the patient's mouth of the prosthetic restoration provided for a specific case of immediate dental implantation of incisors with immediate individual prosthetic restoration [8]. The authors performed a comprehensive literature study on the current state of the described clinical cases of immediate implantation combined in common procedure with tooth extraction and found no similar description and full procedures of this type. If the digitisation is described in the case of such a situation, [11, 16-19, 25-29], it was necessary in each case a two-stage design and installation in the patient's mouth prosthesis separate components. Due to the lack of stability of the implant installation and the uncertainty of its final position after implantation, it was necessary in each of the clinical cases described there to design and manufacture or adapt the abutment and crown only at this stage after implantation. It makes impossibility to perform the whole the implant-prosthetic procedure in one run. In this case there is provided with the design, production and application patient's mouth prosthesis in a process consisting of tooth extraction, implantation along with immediate individual prosthetic restoration. In this way, there is no need to postpone the process of performing the target prosthetic restoration and introducing temporary restoration for a transitional period, which significantly shortens the time of surgery, while repeatedly reducing the recovery time of the patient. Covered by this article method computer-aided design and manufacturing the immediately implant-prosthetic restoration is exemplified by a real clinical case of a female patient with the root canal treated 12 tooth, but ultimately selected for extraction due to irreversible lesions (Fig. 3).

a) b)

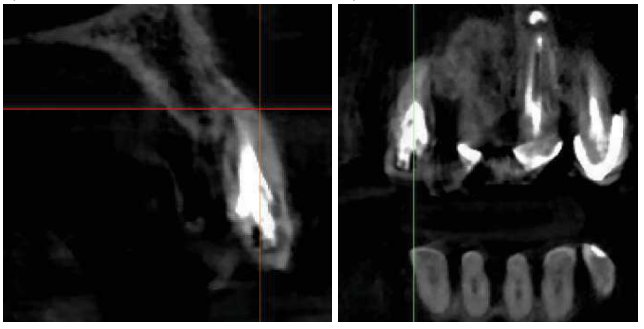


Fig. 3. View of a tooth qualified for extraction on a tomogram: a) cross-section through the alveolar ridge, b) view from the vestibule side

The tooth was not in the periapical change, but have widened the periodontium gap. Qualification of the tooth to realise the treatment plan dentist was accepted by testing using the method of the cone-beam computed tomography (CBCT), resulting in the rated condition of bone tissues and soft tissues around the tooth 12 and the condition of the

tooth. The dentist doing the treatment confirmed after the investigation in the dental clinic that the tooth was not suitable for other medical procedures and qualified it for removal. After verification bone base it was proposed to make treatment plan involving atraumatic removal of the tooth and the immediate implantation navigated, then the installation designed and installation of the before individually constructed abutment and the and temporary crown made of poly(methyl methacrylate) (PMMA). The estimated time of the procedure is about 45 minutes. The manufacturing of surgical guide was scheduled for a preselected site planed for the implant. Next, using only the virtual location of the implant individual prosthetic restoration was fulfilled using the software only. Then, in the dental clinic, atraumatic tooth extraction was carried out, and the procedure was performed using prepared navigational elements.

4. Development of a virtual model of the situation in the oral cavity after tooth extraction

When qualified by the dentist, tooth extraction and dental engineer proceed to analyse the data collected in the CBCT. The width of the alveolar ridge, bone density around the root of the tooth planned for extraction should be assessed, the shape of the alveolar ridge after removal of the tooth and assessment of the constriction sites of the alveolar ridge so as to determine whether the implant can be inserted into the existing bone base. This assessment is necessary to decide whether or not it is possible to perform the implantation in such a way that the implant has a primary stabilisation of 40 Ncm. This assessment is preliminary and eligible to carry out further design work. After a positive assessment, dental engineer commences preparing a digital model of the base of the patient bone (Fig. 4).

In the described case, the isolation of bone tissue from the whole area of the patient mouth was made. This approach allows for betters selection of filter parameters for separating histogram. This task must be carried out precisely because it is necessary to isolate the tooth on each of the slices. The model should be faithful as possible and fully reflects the shape of the tooth, eliminating all flares, thinning and places of borders of individual tissues and material located in the root canal and possibly near the alveolar ridge (Fig. 5). After extracting a tooth model with the base model of the bone must be verified with the shape of the tooth tomogram, to ensure that the model is correct.

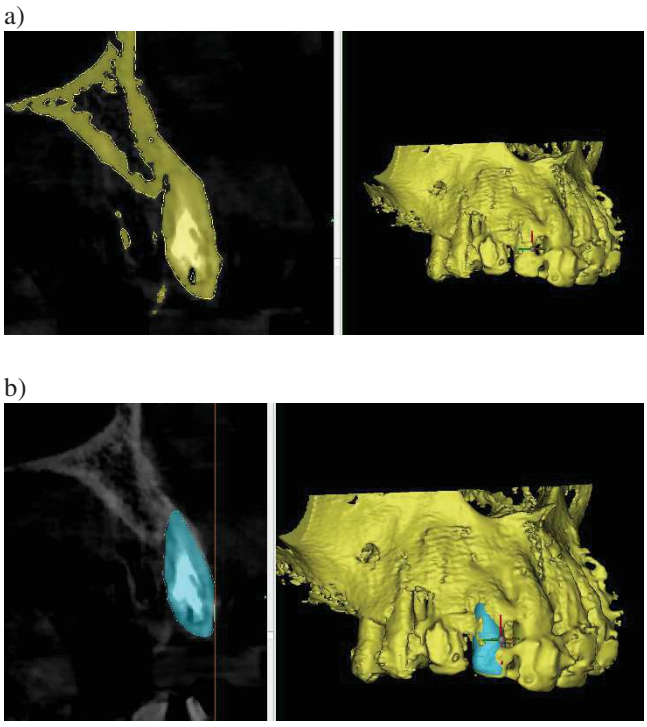


Fig. 4. View of a tooth qualified for extraction on a virtual 3D model of the bone base a) before tooth tissue separation b) after tooth tissue separation

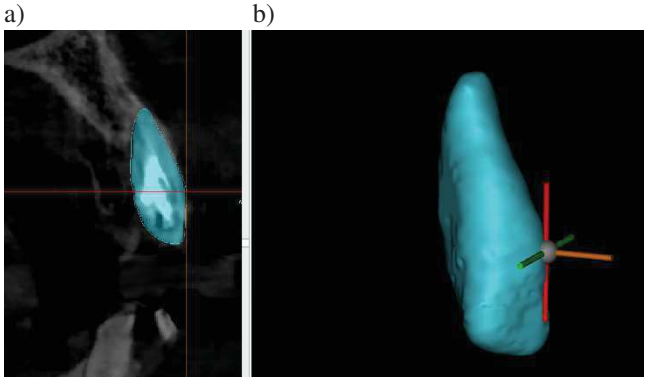


Fig. 5. The model tooth which will be replaced with the implant-prosthetic restoration: a) dental panoramic radiograph, b) 3D model

The final stage of activities is to subtract the tooth model from the bone base model. That's how the model image of their expected above situation, and after a tooth extraction is the basis for the commencement of the surgical template manufacturing. It should be aware that illustrated this situation in the patient's mouth is the resulting forecasting

so that it cannot be verified experimentally. In fact, while the dentist must reproduce it faithfully in the course of the performed surgery. The dentist from this reason must make every effort, that the tooth is removed so as not to damage the bone base, no reduce its volume and break the bone lamina from the vestibule side, in accordance with the assumptions made during the design of the prosthetic restoration. Each described error during the treatment make difficult and because or even prevent the performance of the procedure as a whole and proper placement of the prosthetic components. It is therefore essential that the qualification for immediate implantation is carried out after a thorough intraoral investigation of the tooth and the tissues surrounding it by the dentist. If additional thinning of the bones or lesions is found, it is necessary to make their model, as described above, and subtract the bone base from the model, so that the planned placement of the implant is correct and provides primary stabilisation.

a) b)

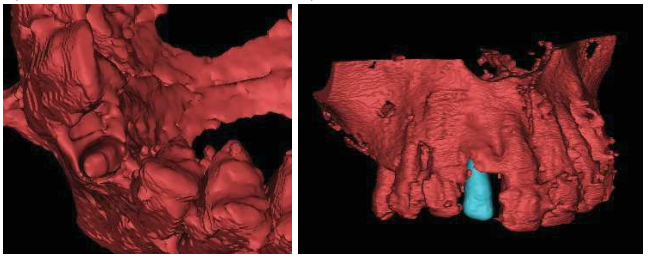


Fig. 6. A view 3D virtual model bone base a) after removal of the tooth with open alveolus b) with the separated 3D model of the tooth

Figure 6a shows the base model of the bone after the scheduled removal of the tooth. An open alveolus is visible. It is worth noting that the CBCT investigation prevents the effective removal of dental attachment tissues from the bone base model. As a result, the model presented in the picture shows an image with a smaller than in reality, an alveolus. The dental engineer must be aware of this by making further actions and adjusting the model accordingly.

5. Designing placement of the implant in place of the removed tooth with a surgical guide

The design of the location of the implant is performed using the bone base model after tooth extraction and is shown in Figure 6b. It was decided to use a standard cylinder implant. The implant should be selected in such a way that its length is maximum in relation to the existing bone base, leaving a margin of bone tissue around the implant of minimum 1mm in each projection [12]. For incisors, it is essential to maintain the correct proportion, preferably less than 1:1 relative to the planned prosthetic restoration height. Due to the lower occlusal forces transmitted by the implant in the anterior segment, the implant does not have to be large in diameter. In many cases, an implant with a 3.0 mm diameter is sufficient. In this case, an implant with a diameter of 3.6 mm and a height of 10 mm was used. The implant was placed in such a way that its crown was wholly seated in the bone base from the palate side. From the vestibule side, the implant is not fully anchored in the bone, making use of the option offered by the selected implant system to leave the implant crown in this way. Such a place was chosen because of the desire to preserve the implant's placed in correct relation to the tips of neighbouring teeth. The space left in this way can be supplemented with bone graft substitute material or tissues located in the alveolus. After healing, it should expect a rebuilt bone base. After verification of the placement of the implant with respect to the axis of the adjacent teeth, the abutment path selecting, the height of the subgingival abutment and the height of the whole prosthetic restoration compare to the implant length, the prepared model is approved by the dentist who is treating the patient. The bone base model, after extraction, together with the implant model, can be used to make a surgical guide (Fig. 7). For this purpose, it is necessary to combine the digital intraoral model with the base bone after tooth extraction with the implemented model of the implant (Fig. 8).

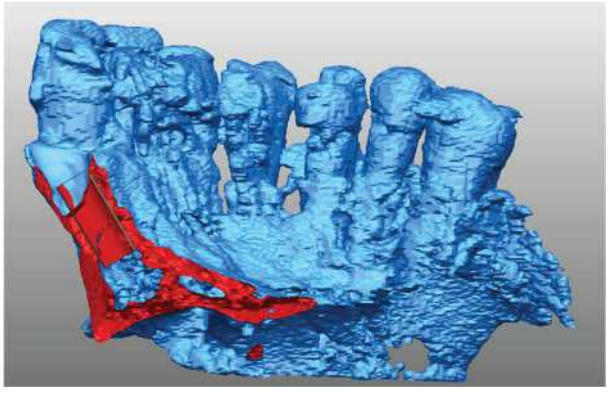


Fig. 7. Planned position of implant placement in the extraction alveolus with bone margins in each plane

a) b)

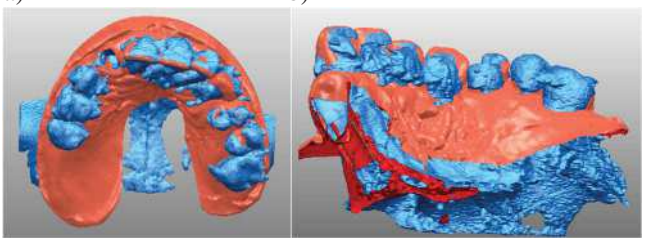


Fig. 8. Virtual models connection of base bone and intraoral made before surgery: a) view of the connection of the bone model with the intraoral model, b) cross-section through connected models with the planned implant position

In this case, it is not necessary to use additional markers to appropriate connection the models [8]. Adjacent teeth are correctly mapped on both models, and their correct connection using the standard three-point folding method is accurate and reflects the real situation in the patient's mouth. To be able to perform a surgical guide is necessary to subtract the removed tooth from the patient intraoral model (Fig. 9).

Fig. 9. A virtual intraoral model with a tooth removed, which forms the basis for making a surgical guide and implant prosthetic elements

Subsequently, the treatment brace is designed using such an intraoral model. Due to the fact that the implant is located relatively deep, it is necessary to introduce deep into the alveolus the material from which the surgical guide is made, so as to ensure the appropriate maintenance of the guide sleeve of the pilot drill. In this case, a standard pilot drill was used, which is used for no navigated procedures. It was decided that it was necessary to use a drill with a minimum diameter of 1.7 mm because the re-placed tooth is 12, for providing enough space for the use of the width of a full navigation system to drill. The model prepared in this way was juxtaposed with the position of the planned implant and the surgical guide was designed with holes on the cusps of molars in order to ensure that the surgical guide adheres during the procedure (Figs. 10 and 11).

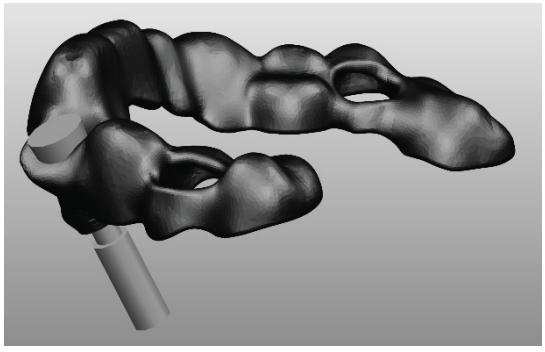
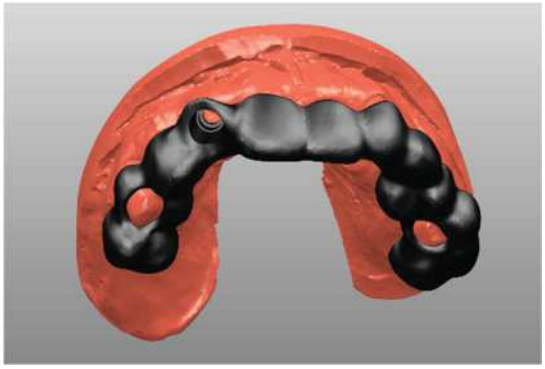


Fig. 10. Model intraoral with the surgical guide model in combination with the position of the implant

a)



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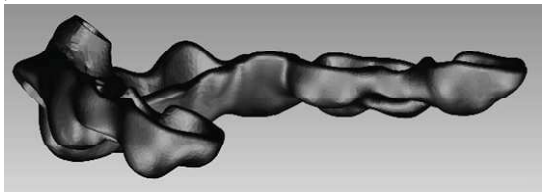

Fig. 11. Ready model of the surgical guide before mounting the pilot drill guide sleeve: a) surgical guide design view on the intraoral model, b) surgical guide design with visible subgingival zone

The surgical guide made of the composite material by 3D printing SLA ensures accurate to 5 μm. Then, with the use of 3D printing selective laser sintering SLS, an individual guide sleeve for the pilot drill was made of titanium.

6. Designing cemented implant prosthetic restoration

Parallel to the manufacturing of the surgical guide, an immediate cemented implant prosthetic restoration consisting of an individual titanium abutment and a temporary crown made of PMMA was designed and built. For this purpose, it was necessary to connect a digital model of the intraoral with postextraction alveolus model and the planned implant with scan-abutment. The model prepared in Figure 12 in this way allows performing the design procedure in a typical way [30-34].

Placement of a subgingival margin was ensured on height approximately 1 mm. The abutment has been designed as an individual angle abutment to ensure its maximum height (Fig. 13).

The only difference to the typical situation was the need to ensure the filling of the postextraction alveolus with the abutment. Any remaining space must be provided after the procedure and the soft tissue sewn, so as to allow their healing in the immediate vicinity of the abutment, as is the case near screws healing. It was manufactured using an industrial CNC milling machine. Then, using its digital model connected with the working model (Fig. 14), the crown was designed (Fig. 15) and milled using a CNC milling machine, making a ready-made prosthetic restoration (Fig. 16).

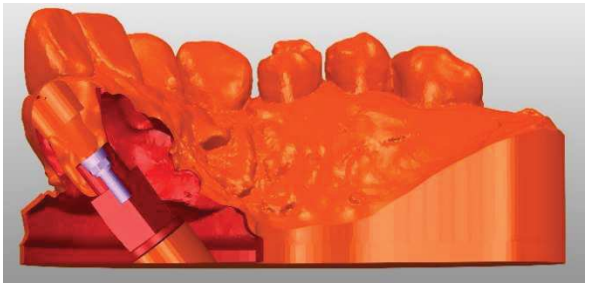

Fig. 12. Cross-section design in an SLA printed working model with visible implant analogue in the planned position

a) b) c)

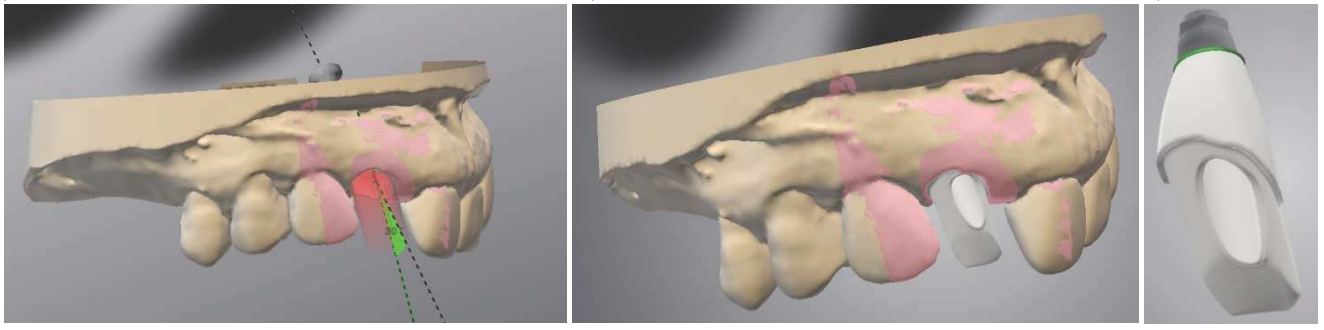

Fig. 13. Exemplary screenshots made during the individual design of the abutment and the finished project: a) view of the abutment insertion path, b) abutment design on the intraoral model, c) abutment design

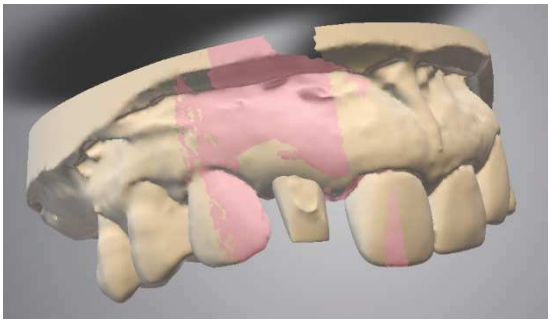

Fig. 14. View of the finished virtual working model enabling the design of a tooth crown

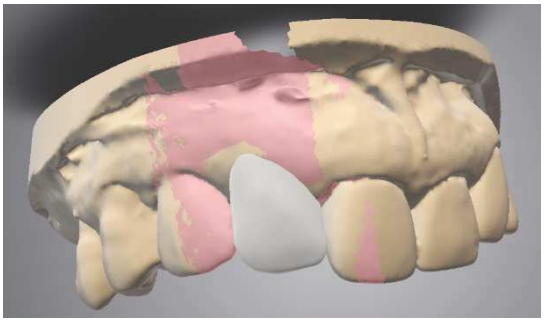

Fig. 15. Ready design of a cemented tooth crown on a previously designed individual abutment

Fig. 16. A ready-made set of elements enabling the entire described procedure to be performed: printed working model, the individual abutment, PMMA temporary crown, surgical guide

7. Discussion and conclusions

Immediate replacing the removed tooth by implant prostheses restoration is a very desirable solution in the market of dental services. The fact of tooth loss very stresses these patients in the anterior segment. In particular, the described case relates to the patient, which holds the remaining anterior teeth. The installation of any temporary prosthetic restoration has many disadvantages, in particular when it is necessary to use a micro prosthesis. In certain circumstances, the described case may also lead to a lack of the possibility of replacing the removed tooth by the dental implant due to loss of the base of the alveolar ridge after tooth extraction. It is mean that the patient needs the bridge on the healthy teeth adjacent, which in the current state of knowledge and technological capability should be treated as the last possibility. It will require a series of procedures to rebuild the alveolar ridge, the effects of which are difficult to predict and the entire treatment are always time-consuming. Current dental engineering allows to plan and prepare immediate individual prosthetic restoration entirely digitally, using data collected in the CBCT investigation. By doing so, the dentist receives the surgical guide allows insertion of the implant in a strictly scheduled place that optimally uses the existing bone base and can perform the correct prosthetic restoration. A prerequisite for the success of such a procedure is to deliver an accurate, atraumatic extraction of the tooth, which will keep the bone base intact. To this end, it is recommended to applied techniques using dental luxator.

Damage to the bone base, in particular, the violation of the bone lamina from the vestibule side will cause that even after performing the procedure following the developed plan, this tissue will die. The implant will not have the correct anchorage in the bone, and the height of the clinical crown of the prosthetic restoration will significantly increase revealing elements of this restoration structure, including, e.g. dental abutment. During the procedure, the dentist must also pay attention to proceed strictly under the assumptions. The implant should be put in place precisely scheduled at the correct height and a right angle, so that made earlier prosthetic reconstruction was in the dental arch.

The appropriate execution of tasks by the dentist performing the procedure is as important as the designing and manufacturing of elements by the dental engineer. In particular, it is important here to maintain the maximum possible precision in the performance of individual tasks related to the creation of the models of bone base and tooth extraction as well as above all, when connecting models using the three-point method. The dental engineer must repeatedly verify the correct positioning of these elements concerning each other. Their incorrect placement will cause significant errors during the procedure. This method is an excellent and accurate way to carry out implantation. However, it must be performed by a qualified person with thorough knowledge of craniofacial anatomy in recognition of bone structures and experience in planning surgical procedures. The software does not allow for guaranteed any independent settings for each item automatically.

A model of the patient's entire dentition is created, based on the collected data. The tooth model planned by the dentist for removal is separated from it. After separation of the tooth model from the whole dentition model is obtained information about the shape and volume of the alveolus, which must be completed by implant and prosthetic restoration. Then the dental engineer verifies the volume of the bone base around the alveolus and finds the place where the implant can be inserted, ensuring that its position corresponds as closely as possible to the axis of the adjacent teeth. The implant's location should be closest to the one where the root of the tooth was previously located. The ability to ensure the maintenance of the original tooth is also verified. The last condition that must be met is to provide the right width of the bone base around the implant.

In the described case, the procedure was performed successfully using the presented navigation and prosthetic elements. The procedure lasted about 35-40 minutes, during which the tooth was removed, the implant was implanted, the abutment was installed, and the cemented crown was used, and soft tissues around the prosthetic reconstruction were sutured. As a result, the procedure brought the expected results, including, first of all, a four-fold reduction in the time

of the procedure, its increased accuracy compared to traditional methods enabling the use of previously prepared prosthetic restoration. It should be noted here that any difference in the placement of the implant relative to the design displaces the crown of the reconstructed tooth as the wake of this in a way that causes the tooth to exit the dental arch either backwards or forwards.

The described procedure is, therefore, also characterised by clinical and medical benefits. The procedure is performed predictably because it is minimally invasive and sparing of patient tissue, shortens recovery time patient and enables a rapid return patient to their daily duties.

Performing treatment using digital procedure planning and surgical guides preparing is, therefore, a right, clinically proven way to replace teeth qualified for extraction.

Discussed the case is an example of the practical application of Dentistry 4.0 idea model because of the need for dissemination this approach, both among patients and dentists. At the same time, an example of this can be an inspiration for dental engineers on a strategy to designing and manufacturing of dental restorations and the development of a modern cooperation model of laboratory producing such restorations with dentists. This modern approach to design and manufacturing such restorations issues forces the dentists to apply advanced methods to diagnose the patient's teeth and to precisely plan and implement implant prosthetic surgery. The article is the author's description of a fully digital approach, which does not require postpones the process of carrying out temporary prosthetic restoration. It is, allowing shorten treatment time and the entire medical procedure immediately replace a tooth by the implant, improving the patient health recovery process as the overall result.

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