ABSTRACT

Purpose: The aim of the paper is to present the method of computer aided planning and manufacturing of a prosthetic suprastructure based on 6 implants in the totally edentulous mandible using digital intraoral scans.

Design/methodology/approach: The method of computer aided planning and manufacturing of the implantoprosthetic restoration in the completely edentulous mandible using digital scans is presented on the example of a real clinical case of a patient with a significant deficit of alveolar bone qualified for the implant treatment. The abutments and the final fixed metal-ceramic bridge was designed and manufactured only on the basis of digital scanning of the intraoral supporting area instead of using traditional impression materials and trays.

Findings: The method of computer-aided design and manufacturing of fixed restorations in the mandible using a digital scan of the supporting area is a powerful technique for improving the treatment process, through which the clinician and the patient may obtain satisfactory results in terms of functionality and aesthetics.

Practical implications: The experience gained by the authors of the article in the technique of computer aided designing and manufacturing of fixed bridges on the basis of digital intraoral scans allows for the formulation of rules that must be followed at both clinical and laboratory stages. The properly performed scanning allows to obtain greater precision of the final restoration in terms of fit and occlusal accuracy.

Originality/value: This paper presents an original methodology of obtaining information about intraoral configuration of the soft tissues and the position of the implants with the use of digital scanning. This method allows for designing and manufacturing of both the abutments and the final restoration without using impression materials which is especially useful in patients with significant bone loss and the gag reflex.

Keywords: Intraoral scanning; Dental implants; Edentulism; Fixed bridges; Implant Abutments; CAD/CAM
1. Introduction

Total edentulism in the mandible is one of the most difficult cases for reconstruction in clinical dentistry [1-3]. The reason for this is the difficulty in obtaining a satisfactory retention and stabilization of the denture on the denture supporting area [4]. From an anatomical point of view, there is only a small proportion of soft tissues available for supporting a denture, because most of the oral cavity is occupied by the tongue. For the biomechanical reasons, the small area of the lower denture causes considerable load transferred to the mucous membrane [5]. In addition, numerous muscles of the cheeks and tongue cause the movement of the prosthesis on the ground while eating, speaking and performing facial gesture [6].

Adverse conditions for the denture deteriorate even more when the teeth are extracted a long time before the final restoration. No stimulation of oral mucosa and alveolar bone with mastication forces leads to bone resorption of the alveolar part of the jaw. As a result of this process a reduction in the vertical and horizontal dimension of the alveolar part of the mandible takes place. This process results in decreasing of the surface of alveolar mucosa and increasing the forces that are transmitted during mastication by the mucous membrane. Reduction of the alveolar part of the mandible leads to forming a shallow oral vestibule and enhancement of muscles of the cheeks and the floor of the mouth. Then, there is an even greater loss of stabilization of the prosthesis [7, 8].

This situation becomes even worse in cases where the tooth loss is a result of periodontal disease [9]. Periodontal diseases are the result of a bacterial infection of periodontal tissue, which in the first stage leads to inflammation and lysis of the periodontium and the alveolar bone. It occurs because the massive loss of the alveolar ridge of the jaw is followed by unfavorable contour of the oral soft tissue [10]. Properly conducted periodontal treatment is able to significantly prolong the existence of the natural dentition. However, the decision about the tooth extraction should not be taken too late, because a long lasting chronic inflammation causes the lysis of the bone hindering prosthetic treatment.

The use of dentures based on the dental implants is a modern treatment modality in dentistry. It should be noted that it is the only treatment concept which allows the most physiological restoration of teeth, as in fact implants replace the root of a lost tooth. As a result, the chewing forces can be transmitted by the implant directly to the alveolar bone, and not, as is widely used in the case of prostheses, settling on the oral mucosa [11].

In the case of totally edentulous mandible implants can serve a dual role. First, they can act as a support and carry occlusal loads on the alveolar bone. Secondly, the implants may be used to improve the retention and stabilization of dentures [12]. In these cases, the chewing forces are still transferred by the oral mucosa and implants prevent only the movements of the prosthesis under the influence of horizontal forces and decoupling of the prosthesis from the supporting mucosa. In the first case an adequate number of implants (at least 4) must be placed to prevent excessive loads on the implants [3]. In the latter case, the number of implants may be significantly reduced. There are cases where the retention of the prosthesis is satisfactory using only two implants [13].

However, patients undertaking the treatment of total edentulism expect the restorations that could be permanently installed in the mouth without any need of taking them out. These reconstructions act very similar to natural teeth in relation to transmission of chewing forces. In addition, there is no need to remove these prostheses, even for hygienic purposes, and it ensures a great comfort for a patient. However, a major problem in applications of fixed dentures on the implants is to ensure the accuracy of the mirroring of the position of the implants in the mouth and considerable precision on manufacturing. Errors can also occur during the preparation of a master cast, on which the final restoration will be produced [14].

A standard procedure is based on intraoral impressions taken with impression copings and impression materials. The impression copings are tightened to the implants. An open impression tray is placed in the mouth. After setting the impression material, the impression copings are unscrewed from the implant through the holes in the tray and remain bound in the impression material. Then implant analogues are tightened to the copings, which allows to prepare a plaster master cast with the recorded position of the implants. This procedure is burdened with errors associated with inaccuracies of the impression materials and expansion of gypsum, which the master cast is made of [15]. Moreover, the procedure is difficult to carry out in
patients with severe gag reflex because it requires introduction into the oral cavity a significant number of components and the impression material.

Therefore, in the classical clinical procedure impressions may be replaced by digital impressions. For this purpose, it is necessary to use so-called "scan abutments" which are screwed directly into the implant, thus providing clear information about the location of the implants. Scan abutments have a simple, repeatable, asymmetrical shape that allows for clear identification of the position of the connection with the implant. Next, the situation in the mouth is recorded using intraoral scanner. The digital impression is then converted into a digital master cast that allows for virtual designing of the implant suprastructure eliminating the possibility of many errors typical of conventional approaches [16].

The aim of the study is to present the method of computer-aided planning and manufacturing of a prosthetic suprastructure based on 6 implants in the totally edentulous mandible using digital intraoral impressions.

2. Clinical case presentation and methodology

2.1. Clinical case presentation

The method of computer-aided planning and manufacturing of the implant prosthetic restoration in the completely edentulous mandible using digital impressions is presented on the example of a real clinical case of a patient with a significant deficit of alveolar bone qualified for the implant treatment. The patient was a man, aged 61, with no medical conditions and a non-smoking individual. The patient lost all his teeth in the lower jaw a few months earlier because of advanced periodontal conditions. The teeth were not stabile and were not eligible for further periodontal treatment. After the extractions the patient was equipped with traditional full removable dentures. The patient accepted the upper denture but complained about the lower denture, which was characterized by a lack of retention and stability. The patient suffered also from gagging, aggravated by the unstable lower denture.

The intraoral examination showed significant atrophy of the alveolar ridge of the mandible in the vertical and horizontal dimension with a very narrow zone of the attached gingiva and shallow vestibule of the mouth and prominent soft tissues of the floor of the mouth (Fig. 1).

The diagnostics included the cone beam computed tomography (CBCT) (Figs. 2 and 3). The process of planning of the position and the size of the implants was performed using computer planning software.

Fig. 1. Intraoral view of the edentulous patient with significant bone loss in the lower jaw, a narrow zone of the fixed gingiva, a shallow oral vestibule and a high profile of the soft tissues of the floor of the mouth

In planning the configuration of the hard tissue and bone density, expressed in Hounsfield units, were taken into account (Fig. 4). The aim of the planning process was to select sites for the implant placement that are characterized by the best geometric parameters, as well as the best bone quality as expressed by its density. In order to
properly choose where to put the implant the planning was also carried out on cross-sections of the bone. Evaluation of the position of the implants in relation to the position of the inferior alveolar nerve in the lower jaw was of particular importance (Fig. 5). Taking into account the available bone it was planned to place 6 endosseal implants in the mandible (Fig. 6).

The patient agreed to carry out the proposed implant treatment using fixed porcelain-bonded-to-metal bridge supported by 6 implants. Due to the strong gag reflex and bad experiences during former treatment with conventional removable dentures, the patient asked for treatment without any impression materials. Therefore, it was decided to carry out the procedure using the intraoral scanner.

![Fig. 4. Planning of the position of the implants in relation to the bone quality expressed by Hounsfield Units (H. U.) – the green colour indicates sufficient bone quality to host an implant](image)

![Fig. 5. Planning of the position of the implants on the cross-sections of the mandible. The red dot represents the inferior alveolar nerve](image)

![Fig. 6. The position of 6 implants planned in accordance with bone topography, bone density and the run of the inferior alveolar nerve (indicated with the red lines)](image)

![Fig. 7. OPG of the patient taken postoperatively showing proper positioning of the implants according to treatment planning carried out previously](image)

During the surgery 6 intraosseous implant were placed in the patient's mandible under local anesthesia (Fig. 7). The surgery and the postoperative period of time was uneventful. After 3 months, the implants were uncovered during a subsequent surgery, and healing abutments were attached to the implants.

2.2. Methodology of digital impression taking and computer aided designing and manufacturing of the implantoprosthetic fixed bridge

After the completion of the surgical phase the prosthetic treatment was started. Firstly, a scan of the entire alveolar soft tissue with healing abutments tightened to the implants was taken with an intraoral laser scanner. In this way, it is possible to register the configuration of the soft tissue around the healing abutments in the same way as it is going
to persist around the final abutments. The resulting virtual model of the mandible was oriented against the model of the opposing jaw in the position registered with the wax bite records (Fig. 8).

Then, 3 scan abutments were attached to the implants in the right mandible and scanning of the abutments and the surrounding soft tissue was performed (Fig. 9). The procedure was repeated on the left side of the mandible after attaching 3 scan abutments to the remaining 3 implants (Fig. 10).

Then, all the scans were combined together to create the final digital model on which further planning process was performed (Fig. 11).

Further on, individual abutments were designed using CAD software taking into account the run of the gum line (Fig. 12). The abutments were made from Ti6Al4V alloy with the use of the CNC milling machine. Scans of each individual abutment were taken in the laboratory setting (Fig. 13).

At a later stage, the abutments were attached to the implants in the patient's mouth. Another intraoral scan was performed with the installed individual abutments. In order
to carry out the scan properly at this stage it was necessary to prepare the individual abutments with the rough supragingival parts that facilitated quick scanning. The scanning should start at the occlusal surface and continue along the alveolar ridge to form a kind of "scaffold". Then the operator should perform an accurate scan of connectors ensuring the most accurate reproduction of all details. Then it is necessary to perform the scan of vestibular and lingual surfaces of the alveolar ridge. Thus, a full image of the intraoral situation was registered (Fig. 14). Because the scan maps only supragingival part of abutments with the remaining parts covered with soft tissues, in order to prepare the project of the final prosthetic bridge it was needed to prepare the master cast unveiling the margin of the abutments (Fig. 15). It should be emphasized that at this stage the abutments may be left attached to the implants and serve as connectors for temporization.

The physical master cast was then milled using a CNC milling machine. On the virtual model the full-contour restoration was designed (Fig. 16), which was then milled out of poly(methyl metacrylate) PMMA using a CNC milling machine.

The temporary bridge was then tried in. Having verified the correct position of the implants on the digital model, accuracy of the dental bridge against the abutments, the shape of the teeth and occlusal contacts the temporary restoration was installed in the patient's mouth. At this stage, if the operator needs to make changes, they can perform an additional scan only in limited areas. If it is necessary to make changes in the shape of the teeth and/or the occlusal surface it should be done on the temporary bridge. Then the bridge must be scanned in the patient's mouth using the intraoral scanner. After verification of the correct fit of the temporary bridge the production process may proceed to manufacturing of the bridge substructure using a CNC milling machine. In this case the bridge substructure was milled from cobalt-chrome alloy. The substructure was placed on the prepared physical master cast and covered with porcelain in accordance with the
requirements of the aesthetics and the occlusion. The bridge was then cemented in the patient's mouth (Figs. 17 and 18). An OPG was taken to confirm proper connections between the prosthetic components (Fig. 19).

The patient accepted the aesthetics of the bridge.

Fig. 18. The intraoral view of the left-side of the fixed metal-ceramic bridge cemented on the implants in the mandible in relation to the opposing full removable acrylic denture

Fig. 19. The control OPG of the patient verifying proper installation of the implants and the fixed porcelain-bonded-to-metal bridge

3. Discussion

The total edentulism in the mandible is a difficult clinical problem that can be solved successfully using the methods of implant treatment [3]. It is particularly difficult in situations when the treatment starts long after the extractions or when there was loss of teeth due to advanced periodontal conditions. Then a significant bone loss requires a complicated surgical planning to select areas the best topography and the best quality of the bone [7-9].

The process of designing and manufacturing of the restoration based on implants requires particular precision due to the need to transfer information about the implant position in the bone to the model [15]. It is a particularly difficult process in patients with a strong gag reflex. The need for a large number of components in the form of impression copings, trays and impression materials makes the process of impression taking extremely difficult in these patients. It is much easier with modern digital methods, in which the impression taking can be replaced by scanning the intraoral situation, which is better accepted by the patient and in many cases allows for a greater precision of the final restoration [16].

Currently, available technology used in dental prosthetics allows for taking all-digital impressions and for elimination of impression materials [17]. This is particularly important in the described case in which the patient had a strong gag reflex and did not tolerate any impression material in the mouth. In addition to improving the patient's comfort during the procedure, the prosthetic digital impression may also ensure a much more accurate representation of the situation in the mouth than the use of impression material and then preparing a plaster model [18].

Own tests carried out on the high-precision materials i.e. polyether polyvinylsloxane (A-silicones) and additive silicones showed that the inaccuracy of the impressions is noticeable in everyday practice and is approx. 0.3 %, which means that the dimensions of the replicated teeth vary approximately +/-0.05-0.1 mm. Another very important factor affecting the accuracy of the master cast is the expansion of gypsum, which in the course of bonding increases its volume up to approx. 0.08%. It means that in the worst scenario the increase in volume of the teeth on the master cast may be in the range of -0.2-0.4%. Thus, aberrations may be seen also on the occlusal surfaces of the teeth. With so big differences in the dimensions of bridges, especially multi-point ones, despite proper accuracy on the model, the bridges do not fit in the mouth of the patient. It is worth noting that the analysis has been executed on good quality materials and according to the manufacturer's recommendations. The model prepared in this way can be scanned in laboratory or may be used for production of a wax bridge that is going to be changed into a metal bridge in the process of casting. Both methods of duplication have their also inaccuracy. In the case of scanning the prosthetic scanner accuracy is approx. 50-70 micrometers. This is a value close to the minimum accuracy of numerical milling machines performing the final model of the restoration. In the case of casting methods accuracy is variable and depends on many factors occurring during the same
process. These processes greatly reduce the accuracy of the work, which must therefore be made with larger tolerances.

The problem described above forces to look for more accurate solutions, which will increase the accuracy of the multiple-point restorations. The first option is to eliminate one of the steps to increase the inaccuracy of the master cast. With the use of a prosthetic scanner it is possible to scan the impression tray eliminating uncertainty of gypsum. However, this method allows for executing the suprastructure of the restoration with greater accuracy and works very well in the cases of very narrow abutments and endodontic posts.

The latest solution, not used on a larger scale, is the use of the intraoral scanners instead of impression materials.

Currently available devices use two separate technologies. The first type of equipment is performing images based on digital cameras with CMOS matrix [15]. The device takes a series of images at different angles together with the movement performed by the doctor along the teeth and using advanced software process to create a three-dimensional model. The software is constantly looking for reference points that allow to refer photographs taken at the iteration n -1 for a picture taken in iteration n. Then, using image analysis, including colour images recorded on created a three-dimensional image constituting the working model for further designing. The presented method of the image acquisition allows to create a very user-friendly software interface. This allows viewing in real time the created model of teeth in full colour. The disadvantage of this solution is the fact that the three-dimensional model is created based entirely on software without measuring. Hence, the accuracy of these scans is lower than of those taken by the second type of devices.

The second type of devices uses a laser beam to create virtual models (as in the case of prosthetic scanners). The head of the device has a source of laser radiation which is reflected and returns from the teeth to the detector which is also located in the immediate vicinity of the head of the laser source [17, 18]. The software analyses the angle at which the beam reflected back and the time of the return and on this basis determines the position of each point in the space. It is therefore a method for precise measurements of distances. The acquired data are processed by the software, creating a three-dimensional model. An undoubted advantage of this solution is the high accuracy of the measurements performed using the laser [18]. Such solutions are used in all precision measuring machines. The disadvantage is the long duration of scanning and the need for meticulous preparation of the area to be scanned. It must be emphasized that both for the first and for the second type of equipment the working area must be perfectly prepared (dried and exposed). Of course, this software also provides real-time preview of the progress of scanning and the created model. Prepared on the basis of the measurement the model can then be corrected by the operator (it is possible to remove overlapping soft tissues of the cheeks and tongue). After this stage, the software makes adjustments. Thus prepared, the digital master cast has a precision of approx. 50 micrometers [14].

In case of impressions for multi-implant restorations it is extremely important to correctly render the position of the implants in relation to each other and in relation to the soft tissues [15, 16].

In the case described above the intra-oral scanner with the laser beam was used. The article shows a very difficult case of total edentulism in the mandible complicated with a significant bone loss and a strong gag reflex. Our case required the use of modern digital technologies, both at the stage of prosthetic and surgical treatment.

4. Conclusions

The method of computer-aided design and manufacturing of fixed restorations in the mandible using a digital scan of the supporting area is a powerful technique for improving the treatment process, through which the clinician and the patient may obtain satisfactory results in terms of functionality and aesthetics. The experience gained by the authors of the article in this technique allows for the formulation of rules that must be followed at both clinical and laboratory stages. Throughout the duration of the scanning, it is necessary to take care to preserve the dryness of the scanned area. The order of scan has a significant impact on the accuracy of copying the shape of the alveolar ridge. Failure to obtain a "scaffold" of the scan will result in a shift of some parts of the scan. A minimum number of scan abutments depends on the maximum number of implants placed in one quadrant. The linkage of the images of the scan abutments and the representations of the soft tissues is done using reference points that are characteristic points of the anatomy of the alveolar ridge. If the margins of individual abutments are planned correctly it is not necessary to use any gingival masks at the further stages of the work-flow. Preparation line extends throughout the entire length of each abutment at the same distance from the top of the ridge. Applying this technique the laboratory time can be limited to 48 hours. The use of the temporary restoration enables the clinician to accurately determine the final shape of the restoration. To improve the
quality of the scan the abutments should be polished only at the subgingival area. The properly performed scanning allows to obtain greater precision of the final restoration in terms of fit and occlusal accuracy. However, it must be emphasized that the scan can also be performed incorrectly and the errors in the scanning process are hardly verifiable. Therefore, the operator must pay attention to carry out the procedure properly.

References


