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# RADIOLOGICAL TEMPLATES AND CAD/CAM SURGICAL GUIDES. A literature review

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**SUMMARY**

Modern digital technologies are changing significantly the classical approach when planning implant treatment. Cone-beam computed tomography (CBCT) and computer-aided design/computer-aided manufacturing (CAD/CAM) based radiological templates and surgical guides allow the clinical translation of the preoperative implant planning. In this review, literary sources concerning the use of radiological templates and surgical guides are reviewed in the dental implant treatment. On comparable bases, modern digital concepts have been explored in their preparation. The advantages and problems associated with their use have been analyzed.

**Keywords:** CAD/CAM, CBCT, intraoral scanner, radiological template, surgical guide

Branemark set scientific foundations of the dental implantology in middle of the last century, and it has been developed very seriously with the advent of digital technology. While in the past, as a successful was considered a treatment, in which the implants in different periods were fixed; nowadays, the implant treatment is laden with expectations to be permanently functional and aesthetic solution for patients with partial and complete edentulism. Since the oral cavity is relatively limited space, high precision in implant placement is very important for successful prosthetic treatment [1]. Misch added that this fidelity must be sought still in planning, to avoid iatrogenic damage during the implant treatment [2]. Poorly positioned or poorly oriented to others implant, often leads to problems during its placement or in the stages of prosthetic construction development. This could jeopardize the aesthetic result or have negative biological and mechanical effect for long term [3, 4]. Translation of preoperative implant planning in the intraoperative clinical stage is the critical point that defines how the results will match expectations. To achieve this in the most controlled environment, visualization and navigation tools are used grouped under the conceptual name of surgical guides.

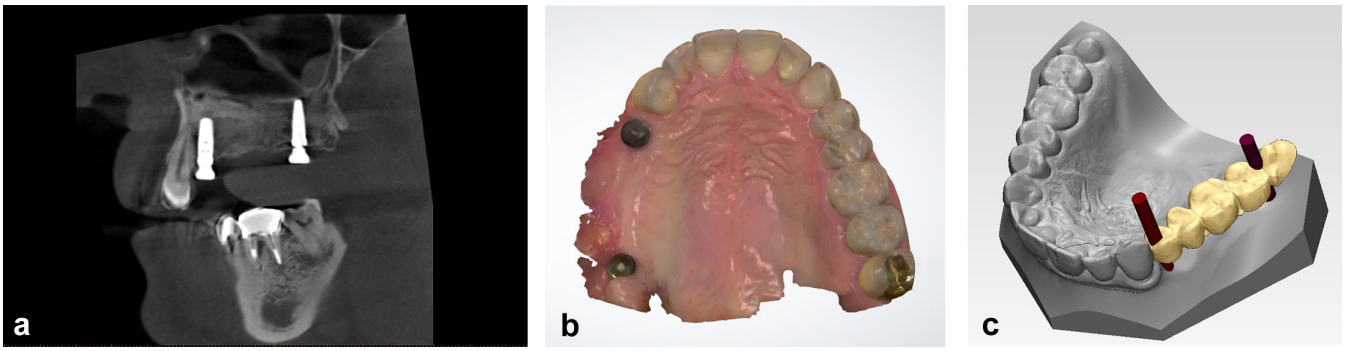
The progress in imaging and particularly the development of CBCT technology allow the production of surgical guides and treatment planning, generally to be digitized. Thus making surgical guides is transferred from classical dental laboratory in cyberspace, where the use of impression materials, plaster casts and polymers – referred to as materials that undergo geometric changes, are avoided. The use of classical impression and casts materials is considered one of the main reasons for the registered differences in the planned and achieved implant positioning using guides [5, 6]. Therefore, so many hopes are pinned on digitization of this process. It is based on classical CAD/CAM technology, and based on imaging (Multislice computed tomography (MSCT), CBCT) implant positioning is defined. Subsequently a guide's model is generated with software, which then is printed with stereo lithography (SLA- stereo lithographic apparatus) or with selective laser sintering (SLS). The traditional approach involves several stages:

1. Developing a radiological template.
2. Three-dimensional imaging (MSCT, CBCT).
3. Implant planning with specialized software.
4. Development of a surgical guide.

Implant treatment is directed towards functional and esthetic restoration of patients with partial or complete edentulism. The final prosthetic structure is the starting point in planning this treatment or in other words, the concept of prosthetic guided implantology is followed [7], as this process begins with the production of wax-up laboratory (Fig.3).

Our idea of where the future crowns will be placed is important as from mechanical - functional perspective the future implants respectively their abutments should be located ideally in the center of the future crowns. This is important not only for maximum resistance to bite force, but also for the aesthetic result. The substantial deviation from this ideal position requires compromises in size and vestibulo-lingual placement for future crowns (Fig.1).

**Fig. 1 a, b and c** - On a digitally reconstructed situation of Figure 1 a and b, it can be seen (c) that the implants are situated prosthetic incorrectly.




A radiological template is molded on the wax-up. The template's purpose is to give a visual representation of the future implant ideal positioning in imaging. This is achieved, as in the central areas of the molded in wax-up- a template an x-ray contrast material is placed directed to the central axis of the crowns. For this purpose, a gutta-percha, metal cannulas, x-ray contrast plastics or varnish may be used. When using the last ones, crowns contours are presented with an x-ray as a guide for planning the implants positioning. Formation process, its variants and radiological image are represented from figures 2 to 7.

**Fig. 2.** Diagnostic model

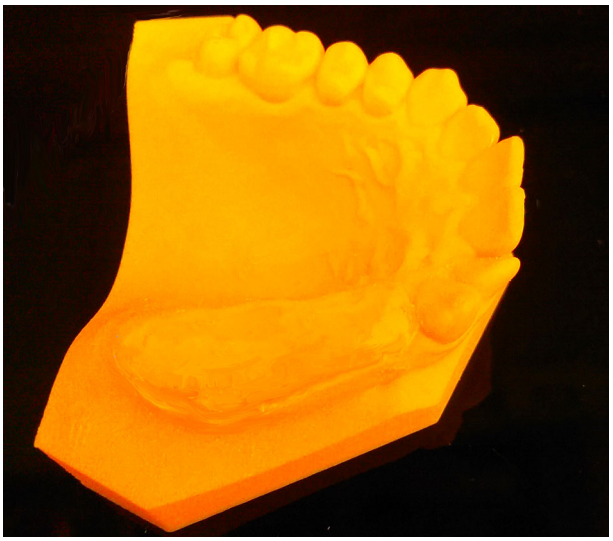


**Fig. 3.** Wax-up on a diagnostic model

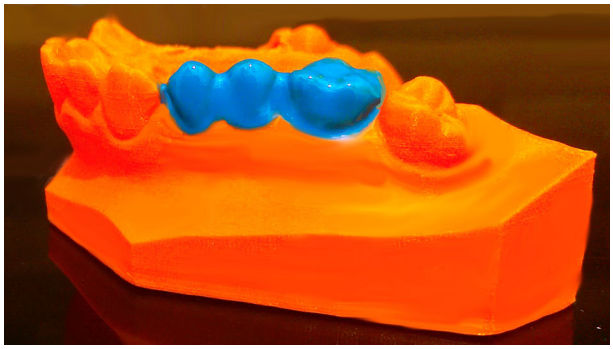


**Fig. 4.** Thermoforming foil with metal sleeves

**Fig. 5.** Thermoforming foil with gutta-percha

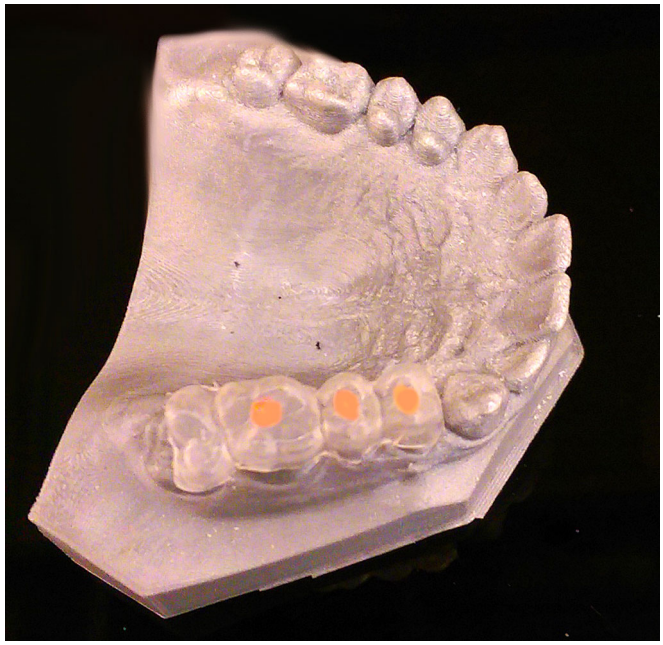
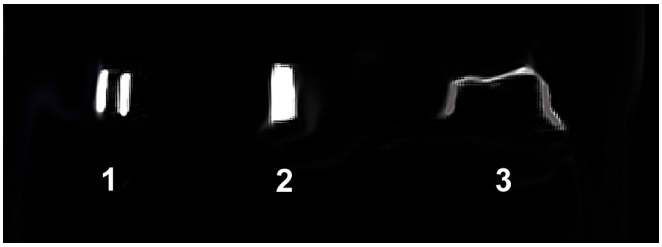


**Fig. 6.** Vacuum-forming foil covered with X-ray contrast varnish

**Fig. 7.** X-ray image of the sleeve, gutta-percha and varnish cover

1. X-ray image of a metal sleeve 2. X-ray image of the gutta-percha; 3. - image of X-ray varnished




Imaging is held with the finished radiological template (Fig.8).

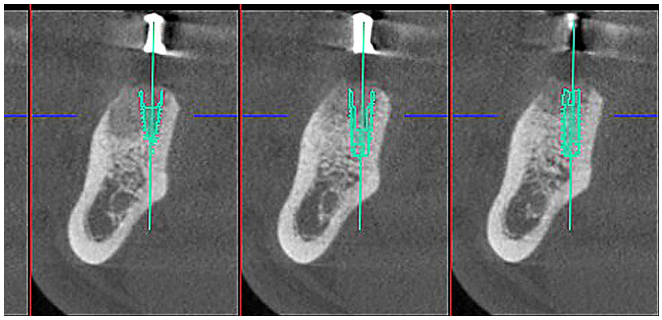
**Fig. 8.** The gutta-percha is contrasting central axis of the X-ray invisible crown.

At this stage, it is important to ensure immobility of templates during scanning, so easily deformable materials (thin vacuum splints or easily breakable plastics) should be avoided because even minor shifts will compromise the planning.

Since the study is three-dimensional, in combination with the x-ray template, it gives us a quantitative and qualitative picture of the bone base in the area of intervention.

The results follow two directions- in one case, under the ideal implant positioning from prosthetic point (marked with template) there is sufficient bone substrate for the implant Osseo integration (Fig. 9).

**Fig. 9.** The prosthetic axis set by markers (gutta-percha in this case) matches with the osseointegration appropriate position of the implant.

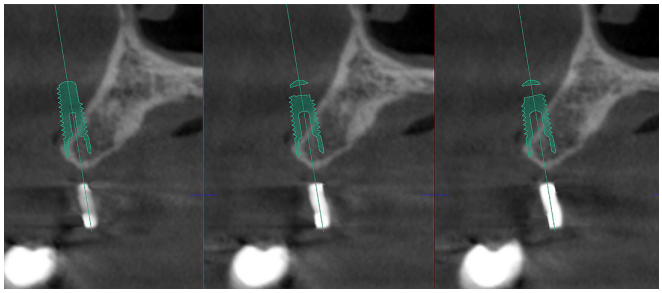


In this situation, we say that the prosthetic and Osseo integration implant positioning match. The next steps are straightforward and clear. We can easily transform the template in a guide (if we have used cannulas practically the template is a guide Fig .10) or we just use them for marking the pilot drill entry point and then, relying on our own manuality and sufficient bone volume, which allows slight spatial deviation to put implant.

**Fig. 10.** Template guide with metal sleeves

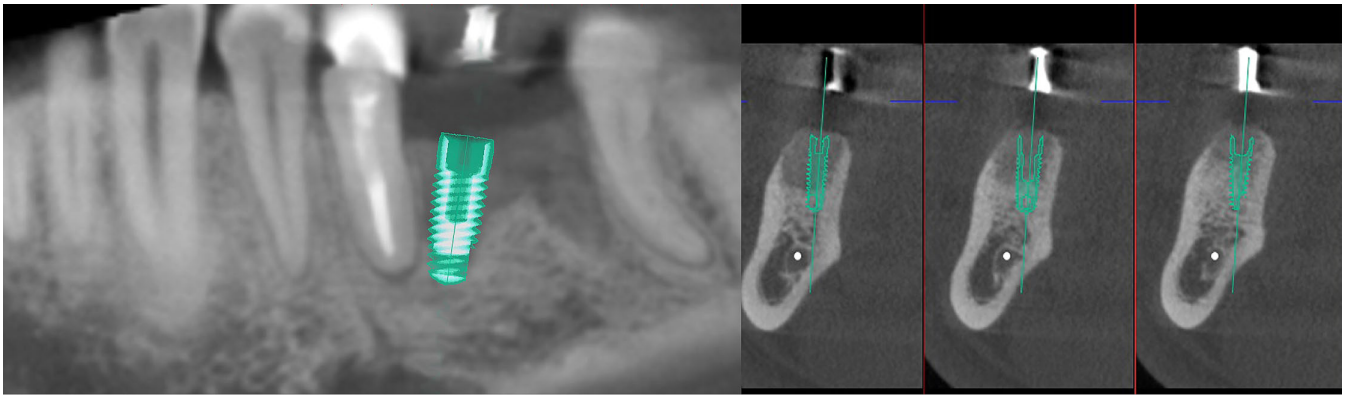
The second case is when both osseointegration and prosthetic implant positioning do not match (Fig.11).

**Fig. 11.** If you follow the axis of the contrast marker implant would be positioned almost entirely outside the bone.



Unfortunately, in practice this is the most common variant, and this is easily explained as toothless areas, in which we implant, are such most often because of the accompanied with osteolysis pathological processes caused the tooth extraction. There is angulation (Fig. 11) or linear deviation in medio-distal or vestibulo-oral direction (Fig.12).

**Fig. 12.** Transverse slices show that the position of the implant according to the contrast template allows its osseointegration, but media-distal inclination of the implant, if put through the template, would be unfavorable to the root of the medial tooth.



**Decisions are two:**

Radiological measurement of the deviation and correction - clinical or laboratory of this deviation. In practice, the clinical correction is more often and it is expressed in a very subjective judgment of the operator based solely on its manuality and its own idea of its magnitude.

The laboratory correction is possible through exotic devices [8] or sophisticated equipment [9] but there is no scientific evidence for its practical applicability, unless the published by the authors of these methods.

A frequent situation where prosthetic ideal implant positioning and its osseointegration do not match, actually makes the use of radiological template, non rationalize and implantologists have to solely rely on their own insight and knowledge about where, what angle and depth to place the implant.

The radiological template, may not serve as a complete surgical guide, but it has intraoperative value by navigating benchmarks remain the clinical ones for the physician (crowns and axes of the adjacent teeth, geometry of the alveolar ridges etc.). The more important is it could be used as a visual reference to the crown contours intraoperative and thus the area, in which to strive to place the implants without it, is "marked" (Fig.13).

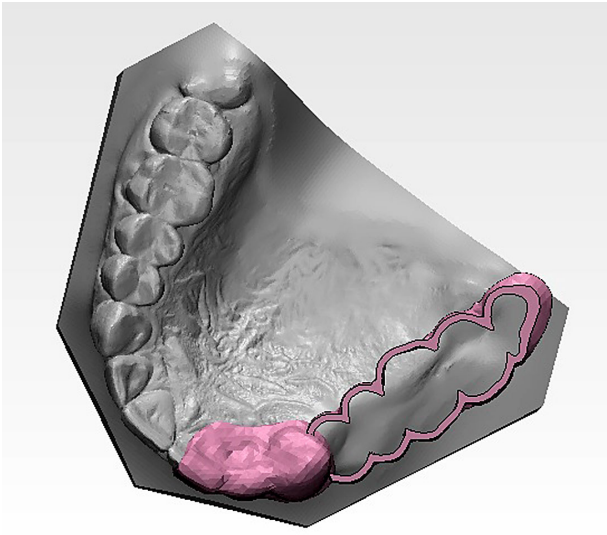


**Fig. 13.** Surgical guide that outlines the contours of the crowns of Wax-up

Not a rare situation in the absence of such benchmark are cases where in search of suitable for its osseointegration position, the implant is positioned so that the aesthetics of the prosthetic structure is compromised (Fig.1).

The next stage is the analysis of survey of 3D images and implant treatment planning.

In modern implantology, CBCT is perceived as the most appropriate three-dimensional method, and this role is defined by numerous studies [10, 11, 12, 13]. Bone zones are analyzed qualitatively and quantitatively in the areas of implantation. Number, size, dimension, type and positioning of the implants, and possibly augmentation procedures are planned.

Crucial for making quality planning is the better knowing the nature of the images, possible artifacts, qualities and shortcomings of the software through which areas of interest are visualized gradually. This knowledge ensures that the implant treatment will be well planned. This means that we are able, based on analysis of images, to choose the right size and type of implants, to determine the clinical and postoperative behavior. Different phases will take place without complications and it will be unnecessary to adapt to unforeseen situations as in the course of implantation to choose the implant's length, for example.

The last stage of implant treatment planning is software design and manufacture of surgical guide. Through it, the planning's translation is performed. It is the link between our planned implantology treatment and its immediate clinical implementation. With its help, the selected implants are placed exactly in the places that we have identified as the most suitable during the planning. They allow us to put them not only in the location but also in the position (inclination to three planes and depth) that we want.

Surgical guides, as well as their very name suggest are the tools for surgical navigation. The common among them, regardless of their diversity, is that they are fixed in the oral cavity and guide the direction of movement, and some limit the depth of penetration of the pilot drill or any ones, necessary to form the bone bed prior to the implant placement.

Depending on the fixation method, they are tooth-, mucosa - or bone supporting guides (Fig. 14-16).

**Fig. 14.** Tooth -supported guide

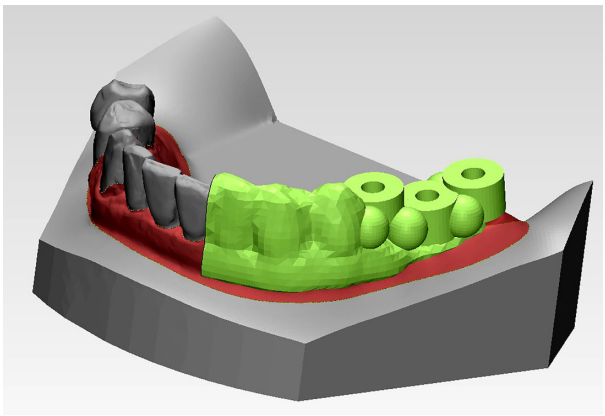


**Fig. 15.** Mucosa - supported guide

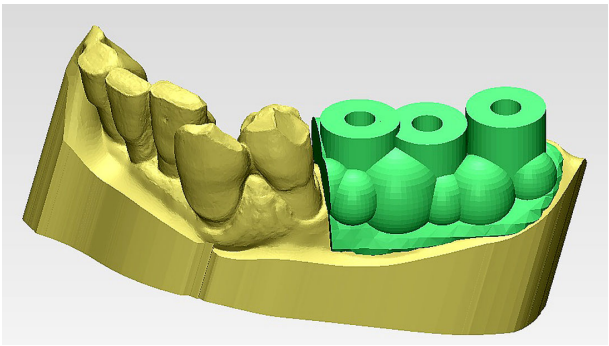
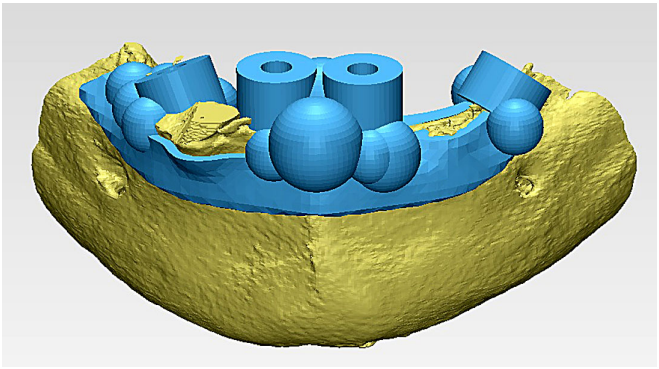


**Fig. 16.** Bone-supported surgical guide



They can be made to the already mentioned analogue manner, based on plaster models (transformation of radiological template in a surgical guide). Alternatively, they are manufactured with CAD/CAM technology, by simply using three-dimensional images of computed tomography study and 3D printing. For the first time, this method of manufacture for the purpose of dental implantology is mentioned in a scientific paper in 2003 [14, 15] and, in essence, is now used unchanged.

The images from CT are the basis for the generation of three-dimensional virtual "replica" of the anatomical area subject to implantation (Fig. 17, 18).

**Fig. 17.** Native-CBCT images

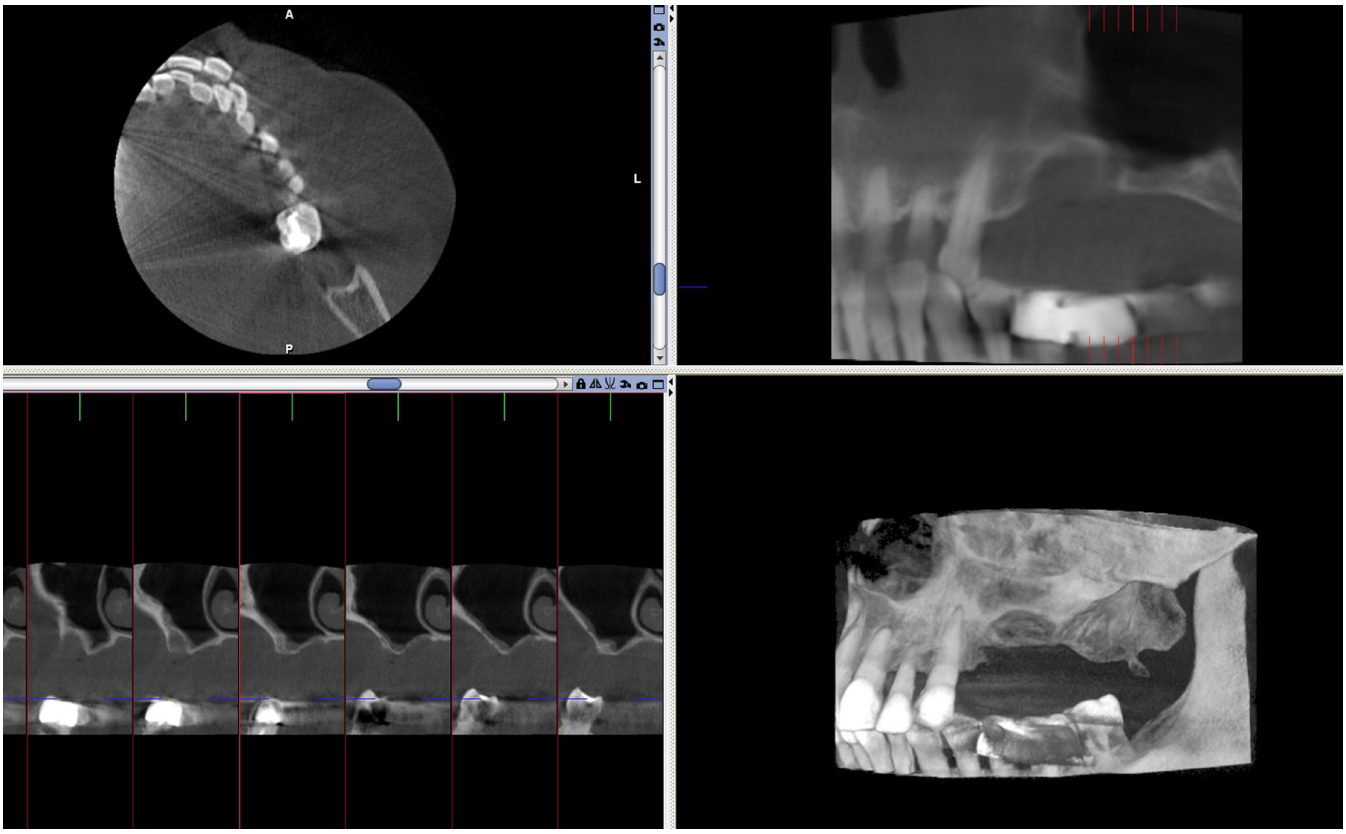


**Fig. 18.** Virtual analogue of the CT images

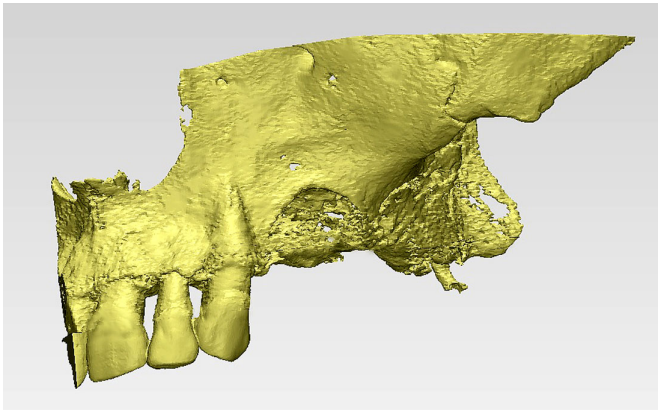
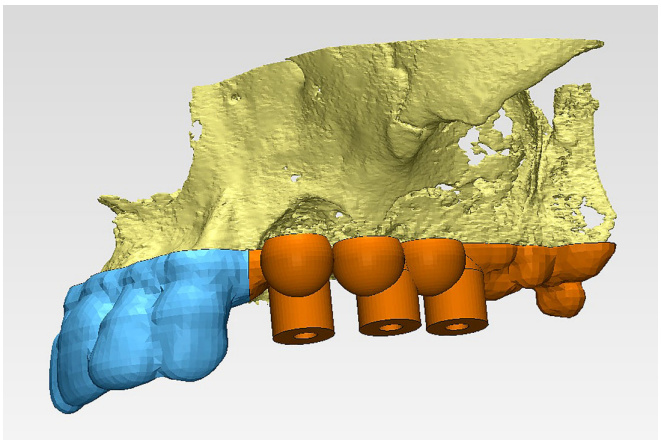


**Fig. 19.** The guide modeled by CAD software. The blue color marked its fixing part, the orange part is the working one, through which are guided the implant drills.



This replica is used to design the surgical guide itself with CAD †software. The guides are composed of two parts – a fixing one, which is located on appropriate supporting part, and a working one where there are openings with a diameter corresponding to the implant drills (Fig.19). The tooth supporting and bone supporting guides are made in this way as in the tomography images mucosa is usually invisible.

For mucosa supporting guides this mucosa is needed to contrast with X-ray scanning or apply the so called "double-scan method" [16]. The first scanning is tomographic (CBCT or MSCT) of the area of interest (the patient). The second one is also tomographic, but the diagnostic cast of the patient from the same area. The images of both tomographic studies superimpose (reposition) on one another, thereby to visualize all of the information within the area of interest, even invisible radiological soft tissue (Fig. 20-22).

**Fig. 20.** CAD image of the scanned with CBCT cast.

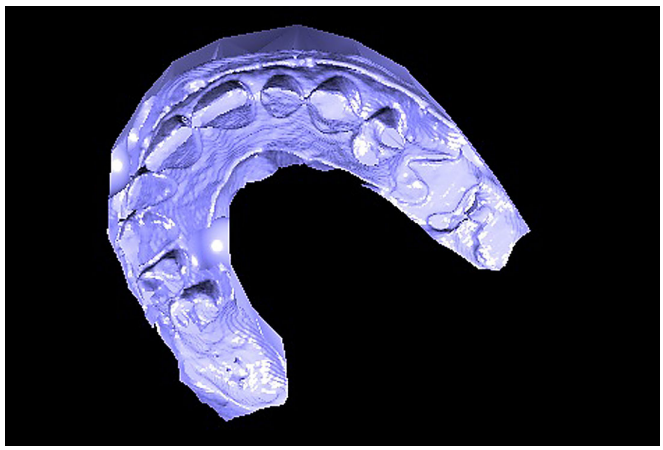


**Fig. 21.** 3D reconstruction of X-ray image of the patient.

**Fig. 22 a.** On both models are marked identical points, by which software superimpose the images. **b.** The superimposed images.

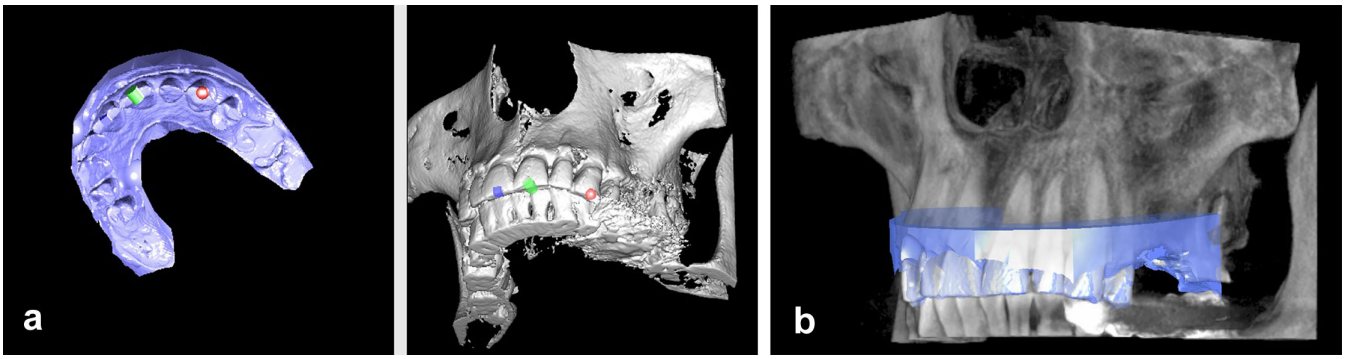
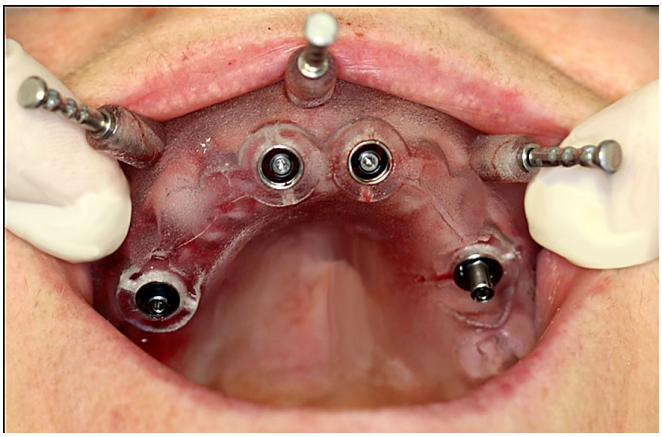


**Fig. 23.** Stereolithografic printed surgical guide.

Once a surgical guide is modeled in the software, it is printed on a 3D printer (Fig. 24). It is printed in one of the two methods stereolithography (SLA) or with laser sintering (SLS). SLA is more suitable for implant purposes, because it allows to be made of transparent material (photopolymer), which further increases intraoperative control and generates smaller spatial deviation compared with the technique of selective laser sintering [17]. Thus, made guide is ready for use.

**Fig. 24.** Surgical guide with fixing pins



The advantages of these guides relative to the conventional and manual methods are several:

• They are more precise by free manual procedures and from conventional guides with respect to the linear deviations from the intended position, angulation and depth of the osteotomy [18].

• They eliminate the need for development of radiological template - a laboratory stage is skipped, which reduces the time to clinical intervention and overall treatment time.

• Trans gingival implants are possible through them, where we want to avoid the flap forming (e.g. preceding augmentation and possible flap would violate the integrity of the surface [19], or we want to avoid postoperative pain and hematoma associated with flap [20, 21]. The latter is especially true for older patients with compromised health [22].

• They provide accurate implant positioning relative to one another.

• They allow proper angulation, which is often indispensable especially in the frontal aesthetic zone.

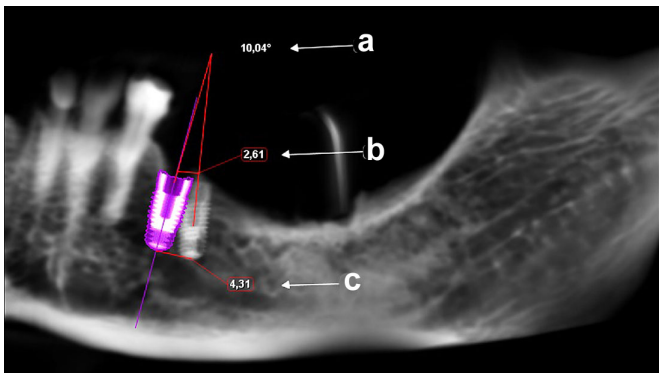
• They allow an osteotomy depth control.

• They allow preoperative preparation of prosthetic design and its immediate fixation.

This way of working has disadvantages:

• Prototype material is hard, rigid, no plasticity to overcome the equator of the teeth (in the case of tooth supporting) or undercuts areas (in bone and mucosa variants). To be stable they need additional laboratory processing and intraoperative fixation. (Fig. 25).

**Fig. 25 a** - angulation between the axes of the implant planned position (the purple implant) and the placed one; **b** - linear displacement in the cervical region; **c** - linear displacement in the apical zone.




• Many often after the guides attachment, the limited intraoral (most often molar) space, makes impossible the introduction of the implant drills into osteotomy area.

• When there are artifacts of prosthetic structures (e.g. metal-ceramic), determining the contours in the fixation areas and development of guides (teeth, bone, mucosa) are impossible.

**Surgical guides' precision**

Question with the precision of CAD/CAM guides has been the subject of many scientific researches [23 - 37]. In all these studies, different variations of the implant positioning compared to the planned ones are established. This position is assessed as linear and angular deviations of the implant axis to the axis of its virtual analogue (the digital replica of the actual implant used in treatment planning). Linear variations are measured in two zones - in the cervical portion of the implant and its apical area (Fig. 26).

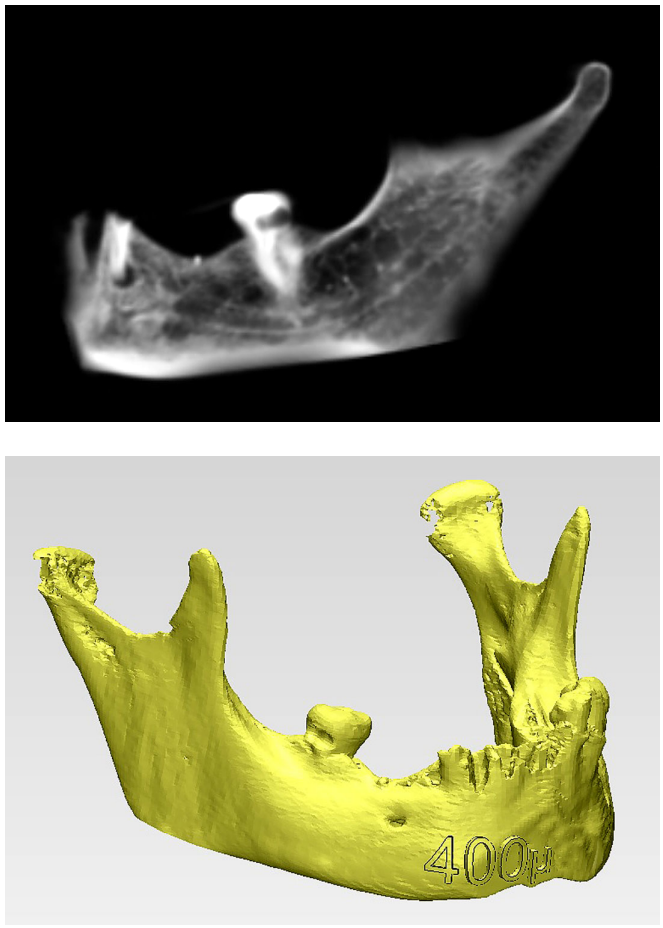
Van Asscheet et al. [38] properly noted that angulation is important, because the apical deviation in the same deviation of the axis would be different for implants with different length. We would add that exactly because of the same reason coronary deviation is important because no angulation can be found, but just parallel movement to the axis in one direction or another, different than the planned one, and again there will be a deviation. The announced results for the registered deviations vary widely. Most studies reported averages, but for the practice the maximum possible deviation is significant, but very few authors have focused their attention on this indicator [25, 28, 29, 32,]. There are cases in these studies in which the angle reaches 8.86 degrees [30]. Linear deviations in the cervical area reach 3.04

mm, and in the apical one reach 5.03 [25]. According to Cassetta et al. [24] the deviation in the maxillary guides is smaller than those used for implantation in the mandible. Their study shows that it is important whether the patient is a smoker or not (it is associated with the more common hypertrophy of the mucosa in smokers and hence a poor stability of the guide). Ersoy et al. registered also smaller spatial variations in maxillary guides [31]. According to Turbush et al. [26] and Arisan et al. [21], mucosa as compared to the tooth and bone are of smaller deviation. Micro movements of the guide during implantation, use of more drills [34, 37], number and distribution of the remaining teeth, height and number of the cannula can influence it [35, 36]. Linear variations in the use of guides and the mentioned conventions lead to errors associated with adverse effects when they are used in dental implantology. Reasons for them can be sought in several directions.

First are the images of CBCT, which serve as a basis on which the guides are made. In some cases, they are directly used to generate the guide contact interface. To be used for these purposes, the primary DICOM files are transformed with CAD software into usable STL files .The latter describe only the surface geometry of objects from the DICOM files. Therefore, if the scanning resolution is low, the surfaces detail of the generated from them STL objects is lower (Fig. 26, 27).

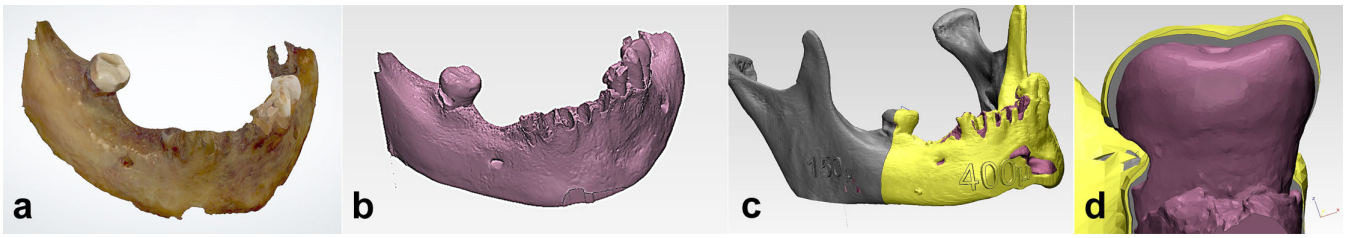
**Fig. 26.** CBCT with a resolution of 150 μ; b-generated by X-ray data three-dimensional STL model.

**Fig. 27.** X-ray image when scanning with resolution of 400 μ and its corresponding STL analogue.




Differences among objects created from images of varying resolution are well illustrated in Fig. 28. A cross-cut section of the three superimposed resolutions (Fig. 28 c) shows that the less resolution is, the better the contour of the real object is followed. The picture with pink color shows the real geometry of the object (scanned with intraoral camera with high resolution); in the picture with yellow color is the object with the smallest resolution (400 μ), and the picture with gray color shows the object with the largest resolution (150 μ). It is clear that the yellow contour follows unevenly surface detail of the real object, as at times it crosses it. If the guide is made according to this contour, it will not be relevant to the real surface and it will be fixed in a position, which is not consistent. The gray contour displays accordance with the actual surface, but it naturally does not coincide with it.

**Fig. 28 a, b.** - a software model of a real object taken with intraoral camera with high resolution (about 20 μ), **c.** The three image superimposed on the lines of coincidence, **d.** Crosscut of the three images with different resolution.




Even with double-scan technique, the accuracy under 150 μ can not be achieved (as the limiting resolution of the best so far CBCT sensors is). Solutions should be sought in the superimposition of images with bigger than the above mentioned resolution.

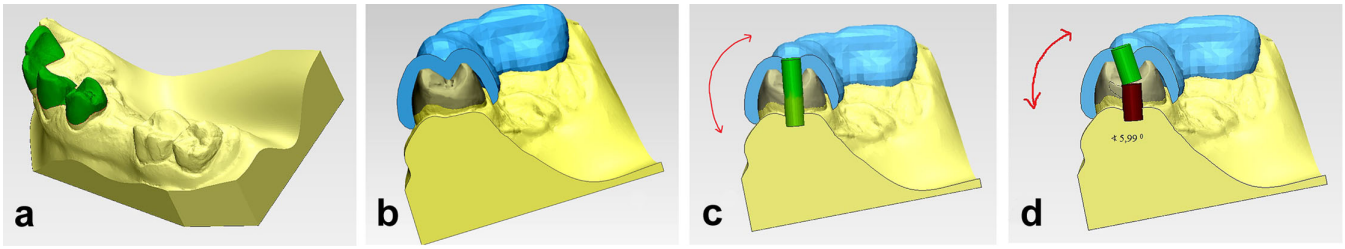
However, which is the limit value, which will provide enough detailed image for making a precise guide? A surgical guide should be considered as a prosthetic construction. Its inner surface must be congruent, to follow the anatomy of the area, for which it is fixed with the accuracy of prosthetic construction. Therefore, we can determine, such as accuracy, the adopted for prosthetic designs accuracy - 50 μ by Gonzalo et al. [39]. In addition, the closer we are to the border in the final product geometry accuracy (the surgical guide), the less deviation from the planned position of the implants we can expect.

The presence of artifacts in x-ray images, as it was mentioned, is an additional factor to generate errors. Especially strong is true that for artifacts of prosthetic appliances, filling material and the canal filling means. They are mainly in the crown areas, and in them - the contours, on which the guide should be generated is difficult or impossible to find. This explains the reported greater accuracy of mucosa supporting guides compared to tooth supporting guides in some studies [21, 26]. The physical receipt of the guide is also a potential generator of error, because end models can be printed with different accuracy. They can be printed with a resolution of more than 25 μ and it can be a cause of spatial correspondence between both surfaces (one of the guide and one of its anatomical analog).

Material from which it is printed is rigid, non-plastic structure, but must be positioned on non-linear, made up of different curves surface, such as anatomical areas of guides' fixation. In addition, while medio-distal and vestibule-oral direction is no problem, its vertical adjustment is impossible because to overcome the equator of the teeth (or vertical vestibular and lingual/palatal ridges in cases of bone and mucosa support). These guides should be completed over the area of the teeth equator, because they lack plasticity to overcome this relief. This makes them movable in a vertical direction and creates an opportunity for different 'stable' positions of the guide, which displaces the position of the planned one of the cannula (Fig. 29 a, b, c, d).

The additional fixing of the guides with locking pins does not solve the problem, because they can be wrongly positioned before fixation. This additional fixation prevents only its further shift in the use of implant drills.

**Fig. 29 a.** With green color are visible equator areas for the development of fixing part of the guide; **b.** Sectional view of the crown of 15 with the generated of the outline of Fig. 29 a guide; **d.** If it can be superimposed the occlusal surface of the guide on the teeth - medial and vestibular, the contact between the two must be released, which creates conditions for micro-mobility and different "stable" positions of the guide relative to the axis of the tooth.




**DISCUSSION:**

The information we receive from three-dimensional imaging is essential when planning implant treatment, but it is not enough to get a full translation of this planning in the clinical setting. This is so, because it concerns the structures that are invisible clinically and intraoperative and we do not have landmarks, which spatially guide us on the anatomy of these structures. The purpose of radiological templates and guides is to help us in this direction. Modern digital methods of intra and extra oral scanning combined with CAD/CAM technologies output production and use of new qualitative level. Despite their proven advantage, compared to manual methods, their application, however, is associated with fluctuating results. The registered deviation in the use of surgical guides sometimes reaches values, which if security zones, as distance to critical structures are not provided; it could lead to unintended consequences.

Analysis on the literature data refers theoretically to three main problems, related to spatial variations in the use of these guides:

1. The low resolution of the scanned images should be overcome;

2. The influence of metal artifacts, where there are such, should be neutralized on anatomical structures in areas of interest;

3. Impression material should be used, which has a dualistic characteristics - to be flexible enough in areas, where the vertical relief have to be followed (its fixing part), and at the same time sufficiently rigid in the zones, in which implant drills will be used (the working part).

Solution of the first problem is an answer of the issue with the quality on the base, from which the implant planning starts. An image with a resolution or surface detail of the order of 50 microns would be an ideal matrix for software modeling of the surgical guide, which subsequently will be fixed on its anatomical analogue with sufficient accuracy.

The second task concerns the universality of surgical guides' application. Artifacts in CBCT are very common problem and overcoming their influence would make surgical guides reliably applicable to all patients.

The third issue is perhaps the most important, because in our opinion is the most largely responsible for registered variations in the use of surgical guides. Its decision will allow secure intraoperative fixation of the guide and in position, which will fully coincide with or have minimal deviation from the planned one.

Aforesaid confirms the finding of a number of authors, who concluded in their researches, that CAD/CAM based guides need further improvement and that are necessary further researches to clarify and resolve problems associated with their use [8, 17, 21].

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