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Review article

Original computer aided support system for safe and accurate implant placement—Collaboration with an university originated venture company

Taiji Sohmura [a,*], Yoich Kumazawa [b]

[a] *Division of Oralmaxillofacial Regeneration, Osaka University Graduate School of Dentistry, 1-8 Yamadaoka, Suita 565-0871, Japan*
[b] *Bionic Co. Ltd. 2-7-14 Higashiawaji, Higashiyodogawa-Ku, Osaka 533-0023, Japan*

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Summary An original implant surgery support system with computer simulation to determine the position of implant placement and fabrication of a surgical guide that helps in bone drilling was developed by collaboration of Osaka University Faculty of Dentistry and Dental Prostheses Fabrication Company. A virtual reality haptic device that gives the sense of touch was used for simulation and a surgical template was fabricated by CAD/CAM method. A patented technology enabled to remove artifact due to metallic prostheses by replacing the damaged teeth of CT image by precise 3D measured image of dental cast. Surgical guide was designed using haptic device and fabricated including bone model by a computer-aided rapid prototyping modeling machine with a UV-cured acrylic-based resin material.

Two clinical cases with implant placement on the three lower molars by flap operation using bone supported surgical guide and flapless operation with teeth supported surgical guide and immediate loading with provisional prostheses prepared beforehand are introduced. The present simulation and drilling support using the surgical guide may help to perform safe and accurate implant surgery.

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* Corresponding author. Tel.: +81 6879 2915; fax: +81 6879 2915.
E-mail address: sohmurat@dent.osaka-u.ac.jp (T. Sohmura).

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1. Introduction

In these days, the number of patients who hope for the implant remedy has become increased due to upcoming reliability to the recent implant materials and methods of surgery. Whereby, the number of dentists who aim at the acquisition of remedy for implant has increased rapidly. In this circumstance a computer aided surgery support system that determines the appropriate implant placement position and guides safe and accurate operation in the surgery has become intensely anticipated [1—4].

Some foreign systems that use surgical guide have already been applied domestically [5—8]. We have developed an original CAD/CAM dental implant placement simulation and surgery support system "BoneNavi" by a collaborative work with a dental prostheses fabrication company. Then, we founded a university originated venture company "Bionic" [9—11]. The feature of our system is to develop an original artifact removal system.

At present, acquisition of CT image has become generally done, and the transformation to 3D (three dimensions) image has been carried out to simulate implant placement and produce surgical guide.

However, the bothersome problem in the CT image is the artifact that is the noise originating from the metallic restoration in patient's mouth [12,13]. The patients who hope for the implant treatment almost have some restorations in the mouth, and the probability of the metal is considerably high. Especially, strong noises are emitted when multiple restorations with high density precious metals exist, and the images of the jawbone and dentition are severely damaged. Fig. 1 shows an example of the artifact. The artifact originates from the metallic restorations in the mouth, and spear-like stripe noises appear along the direction of the incidence of X-rays and irradiates on the image of the dentition and bone. As a result, the implant simulation using the CT image with artifact becomes impossible or inaccurate. Some processing to remove artifact is attempted, however, it is not effective for a strong artifact [14,15].

Then, we have developed a method to remove artifact by substituting the damaged dentition of the CT jawbone image with cast model image measured by high precision optical 3D measurement system [16]. Moreover, this technology is very useful to produce a precise dentition support type surgical guide. The dentition supported type means a guide that was installed on the remaining dentition in the bone drilling. To produce precise surgical guide of this type, 3D measurement in the dentition with high accuracy is indispensable. However at present, dentition image on the jawbone measured with CT is not so accurate, and it cannot be applied satisfactorily. Accordingly, we have developed the above-mentioned precise surgical guide.

Our system has already experienced for more than 700 clinical cases, and in this review we introduce the method and clinical cases.

2. System and method

Initially, a resin bite interface as shown in Fig. 2(a) was devised. This was used to replace the dentition image in the CT jawbone with 3D image of dentition of working cast measured by precise optical measurement system. Gypsum plate indicated by an arrow was used for a positional registration of both images.

This was installed in patient's mouth as shown in Fig. 2(b) and CT imaged. In the transformation of the DICOM data into 3D CT image with the bone imaging condition, the resin interface became transparent and disappeared, but the gypsum plate for a positional registration was imaged by this condition. Then, the interface was installed between the casts as shown in Fig. 2(c), and maxillary and mandibular casts including interface were measured by a precise optical 3D shape measurement system (RexcanARX, Solutionix) as shown in Fig. 3. This optical measurement system uses the halogen light and projects encoded striped pattern to the measured object. The pattern is received with CCD of 2 million pixels and transformed to 3D data automatically with precision of a few micrometers. However, in the optical method it is impossible to measure the whole image of dentition at one shot due to the shadow by complex shape and undercut of dentition. Then, the object is rotated with four axis driving device and measured. The data measured

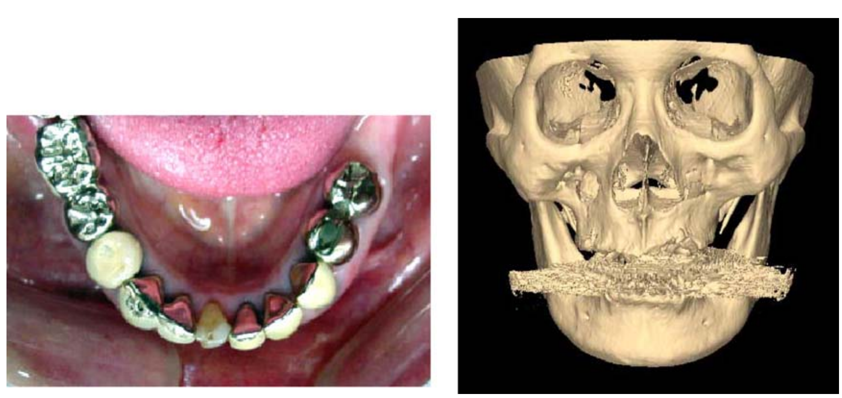

Figure 1 Photograph of an oral cavity with metallic restorations and its 3D-CT image.

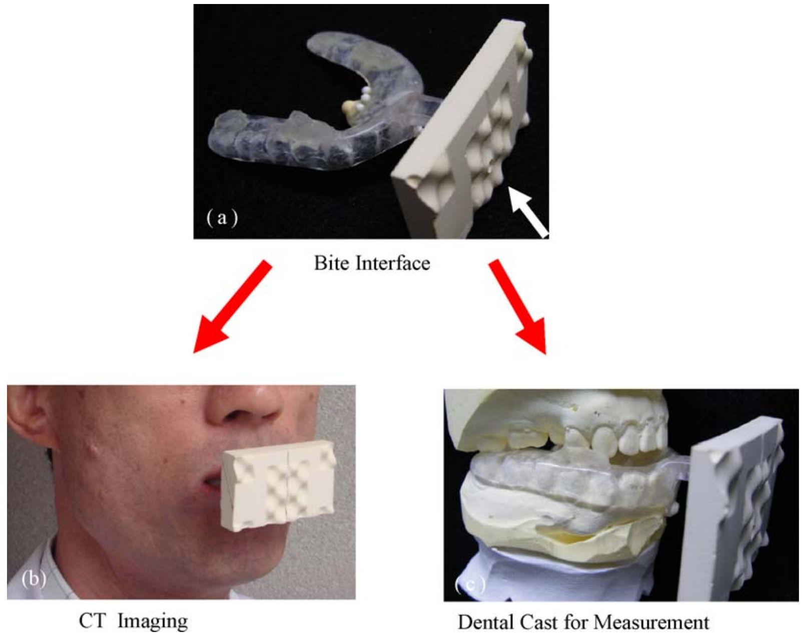

Figure 2 Bite interface and CT imaging and cast model measured.

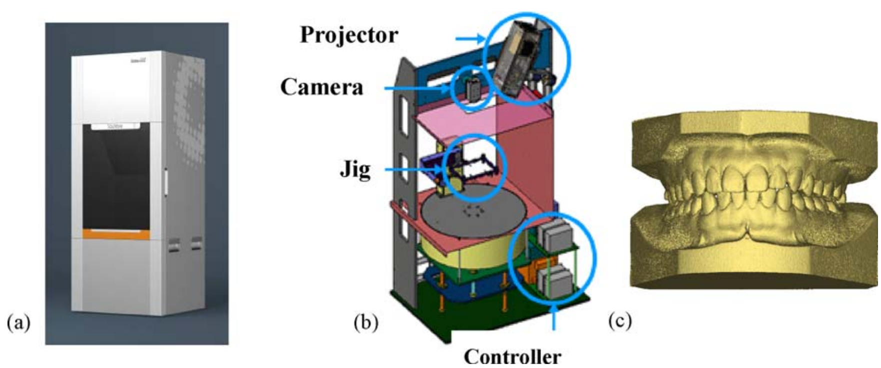

Figure 3 High precision 3D shape measurement system. (a) Exterior view; (b) internal mechanism; and (c) measured cast model

from multiple directions were merged to compose the whole 3D shape without defects. For instance in the case of one cast, measurements from 20 directions were calculated and merging of data was carried out, and complete image was obtained within about 15 min. CG (computer graphics) of a merged cast is shown in Fig. 3(c). 3D image of dentition with high accuracy and without defects were completed.

Then, this cast image was positioned to the dentition in the CT bone image by fitting the image of plates indicated with white arrow shown in Fig. 2(a) by using a software. Afterwards, the shape of dentition of the CT image was removed, and it was replaced with the image of cast. By this method 3D image of bone with high accuracy dentition without artifact could be obtained. The accurate simulation of the implant placement and CAD/CAM production of the surgical guide became possible by using these data.

Another feature of our system is that these processes are operated by virtual reality haptic device shown in Fig. 4(a) using exclusive software (FreeForm and PHANToM, SensAble Technologies, Woburn, USA). Several virtual tools for drilling or cutting are equipped in this software, and by pressing the button indicated by an arrow on the manipulator we can process the objects by feeling the sense of touch such as bone cutting and drilling [17—19]. By applying this device and software, we could simulate implant placement considering the condition of bone, antagonistic and proximal teeth, and also design surgical guide [20].

Further, to fabricate the surgical guide and bone model we used a characterized RP (rapid prototyping) equipment (EDEN260, Objet, Rehovot, Israel) shown in Fig. 4(b). This device accumulates acrylic resin by thickness of 16 μm and polymerizes with ultraviolet lamp, and enables to fabricate free form models with high accuracy. RP equipment was developed for industrial use to fabricate a prototype promptly to check the design error in CAD data. Conventionally, fabrication of a prototype is done by the cutting method, however, a complex free form object is impossible to fabricate in the cutting method. Then, a novel RP layering method that transforms CAD data to the slice data and accumulates and fabricates them was developed. At present, the material for this layering method extends widely such as gypsum, resin and metal. We selected the present equipment since the thickness of layering is extremely thin and accuracy is high.

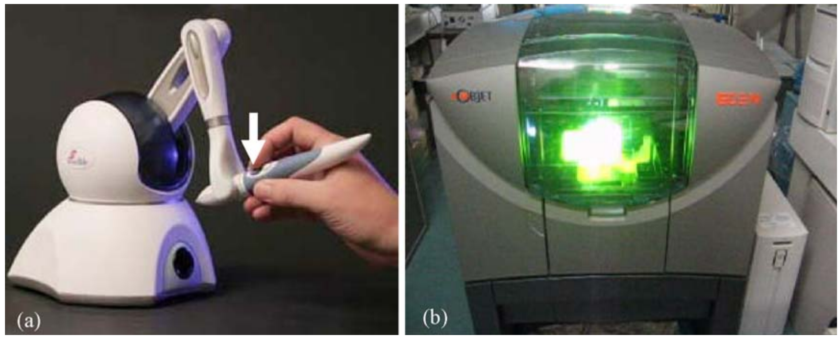

Figure 4 VR device and RP machine. (a) VR device "PHANTOM-Omni" for implant simulation and CAD of surgical guide; and (b) RP fabrication machine "EDEN".

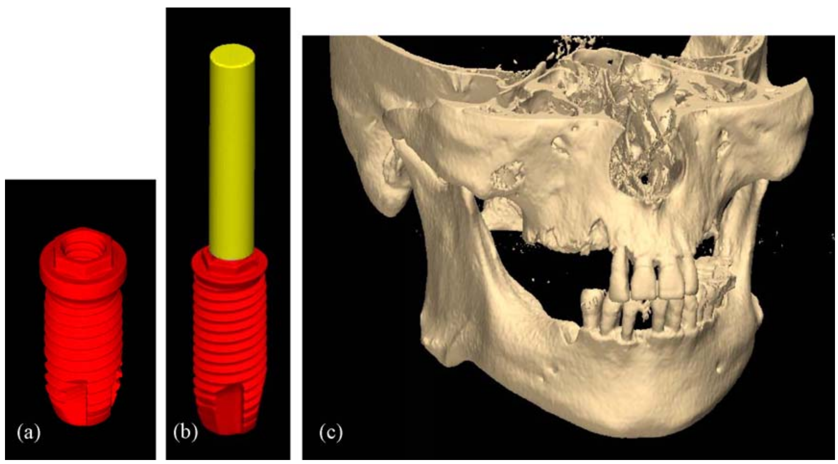

Figure 5 3D-image of bone and implant.

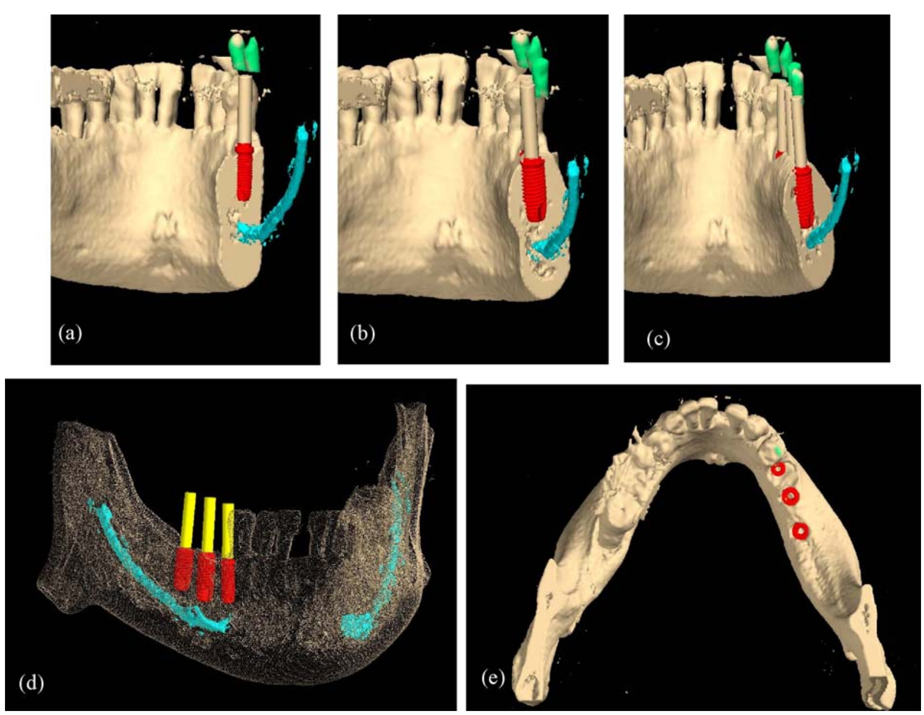

Figure 6 Simulation of implant placement.

Unlike the cutting method, RP equipment can produce multiple objects in parallel work at the same time, and then two or more surgical guide can be efficiently produced. Moreover, it is very advantageous that even the complicated shape such as bone model can be produced.

As mentioned above an original support system "Bone-Navi" is possible to simulate implant placement and help accurate and safe surgery by surgical guide. In this system CAD and CAM of the surgical guide can be done by the dental laboratory. However, the simulation to decide the implant placement position is the work of the dentist. Introduction of haptic device and software is somewhat costly for general dentists, and the operational software for haptic device is not an exclusive one for implant simulation.

Then, we developed another general system that the dentists simulate implant placement by using commercially available implant simulation software (10DR, 10DR Japan, Kobe, Japan). The results are transferred to the dental laboratory, and the surgical guide and bone model can be fabricated by CAD/CAM technique using PHANTOM and RP equipment [9,10]. Then, the products are delivered to the dentists.

3. Clinical application

Clinical case-1: Implant placement on the position of mandibular molars by flap operation using bone supported surgical guide.

The 3D CT image of the patient's jawbone was introduced in the software FreeForm as shown in Fig. 5(a) and the implant placement was simulated by using haptic device PHANTOM. 3D images of oral implants measured by micro-focus CT shown in Fig. 5(b) and (c) were also introduced in the software. The direction indicator to show the orientation of oral implant was added (Fig. 5c). Three implants were selected and manipulated by the haptic device and placed in the bone considering its quality. The cross-sectional image of the bone was helpful to determine the site of placement as shown in Fig. 6(a—c) for the lower right second premolar, first molar and second molar, respectively. The position of mandibular canal was detected and shown in cyan color. The distance between the apical end of the oral implant and mandibular canal could be determined using the measurement tool in this device. The CG image after simulation was shown from frontal view in Fig. 6(d) with half transparent mandibular bone, and from occlusal view as shown in Fig. 6(e).

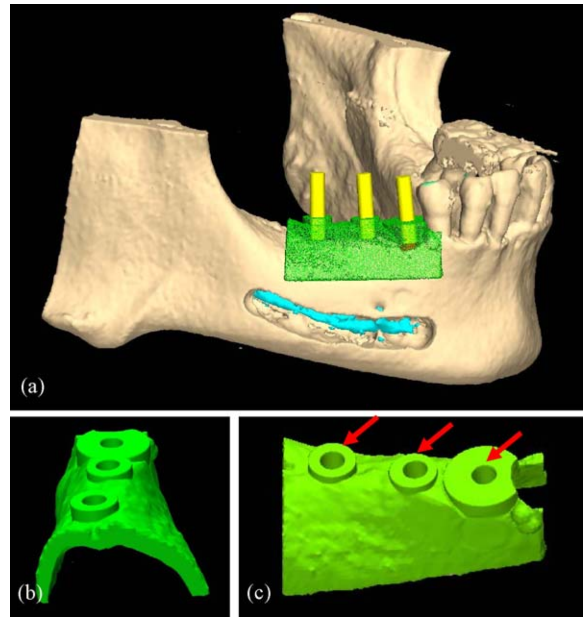

Figure 7 CAD of surgical guide.

3.1. CAD/CAM of the surgical guide

A hogback-shaped solid object serving as the surgical guide was applied to the bone image with oral implants, as shown in Fig. 7(a), where the guide was drawn as a half transparent image. The shape of the bone and the direction indicator of the oral implants were subtracted, and the surgical guide with the impression of the bone and the direction indicators could be designed as shown in Fig. 7(b) and (c). The impression of the direction cylinder was designed to serve as guide holes for bone drilling. In order to regulate the depth of drilling, the column stage as shown by the arrow was also designed. The CAD data of the surgical guide were converted into STL data format and transferred to the RP machine. The surgical guide was fabricated with resin layer by layer, as shown in Fig. 8(a). The stainless steel guide tubes were adapted in the guide to avoid the scraping off the guide while drilling, and the edge of the guide was trimmed to avoid irritation to the mucosa. 3D image of the bone was also converted into STL data, and the bone model with a trimmed open window to show the mandibular canal was fabricated.

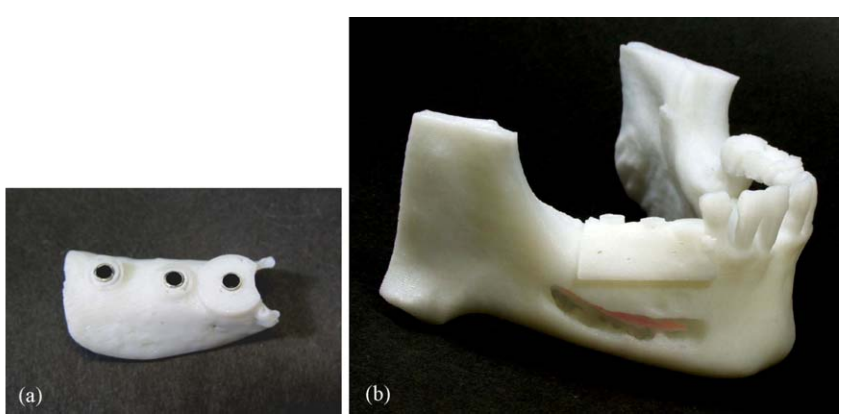

Figure 8 Fabricated surgical guide and bone model.

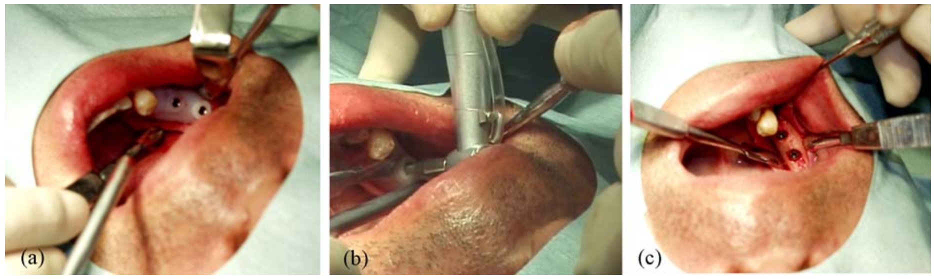

Figure 9 Surgical operation of implant placement.

The surgical guide could be adapted firmly on the bone model as shown in Fig. 8(b).

3.2. Clinical application of the surgical guide

The surgical procedure for implant placement applying the present surgical guide was carried out as shown in Fig. 9. In this case operation was done by flap operation, then the overlying mucosa was incised and the bone was exposed. The surgical guide was set up on the bone as shown in Fig. 9(a). The operator also reported that the guide was placed on the bone stably, and he did not feel any instability.

Guided by the surgical guide, the initial mark on the cortical bone was done by round bar and the hole was drilled by twist drill with 2.0 mm diameter, as shown in Fig. 9(b). The surgical guide was then removed, and drilling with 3.3–4.8 mm-diameter tools was done by free hand following the preformed hole. Finally, the implant bodies were inserted as shown in Fig. 9(c). By using the present simulation and surgical guide developed, the implant could be inserted safely and accurately [21].*Clinical case-2*: Case of three implants placement on the position of mandibular molars by flapless operation that uses dentition supported surgical guide and immediate loading by provisional restorations produced beforehand.

Case-1 is the example of first clinical application of our system that simulated the placement of the implant by using PHANTOM. However, the majority in our recent clinical applications is simulated by commercially available implant placement software, and CAD/CAM of the guide and bone model is done by PHANTOM and EDEN. Moreover, though Case-1 was done by an orthodox flap operation, the cases with the low invasive flapless operations and immediate loading with provisional restoration have been increased recently [7]. However, if the simulation is not done accurately, it is likely to lead to the malpractice because in

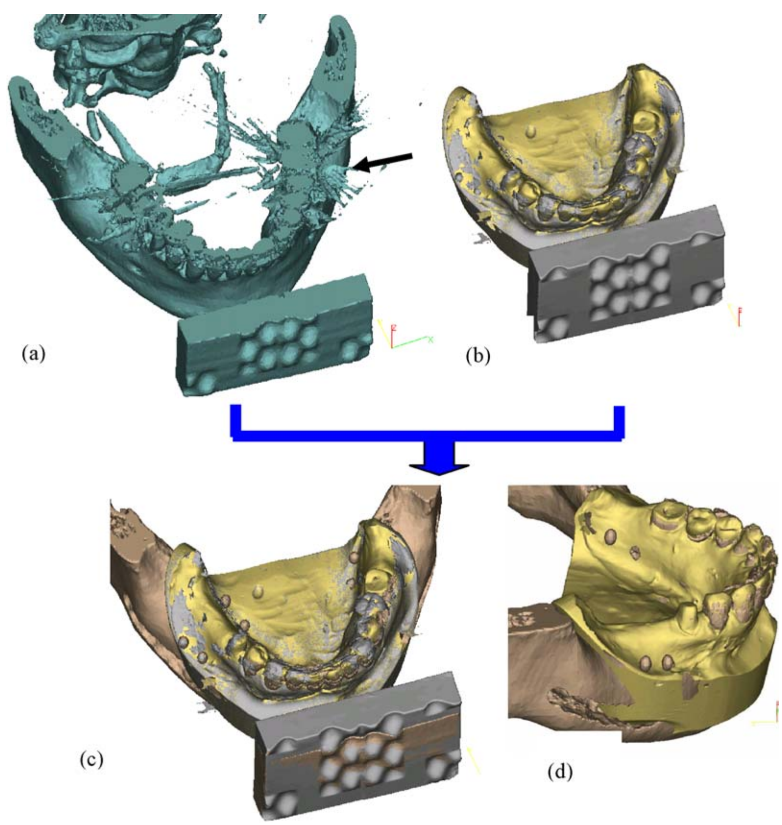

Figure 10 Artifact removal by replacement of damaged CT image with 3D measured dental cast image.

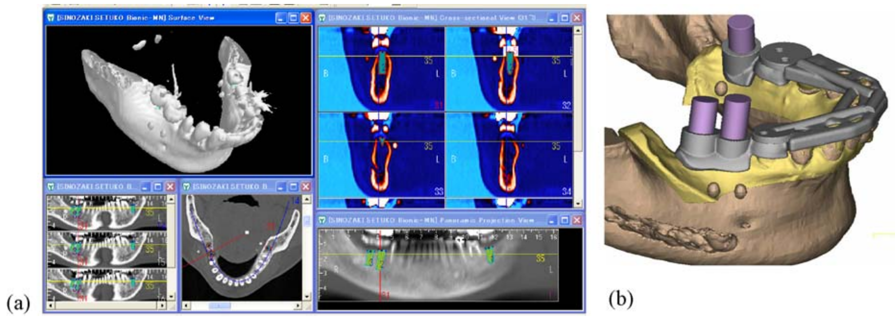

Figure 11 Implant simulation by using the commercial software (a); and CAD of the surgical guide (b).

flapless operation drilling is done without observing the bone directly. In such cases our method developed will support safer and more accurate surgery.

Case-2 is the example of such clinical case, and implants placement on the mandibular three molars in 46, 47 and 37 were intended. CT jawbone image of the patient with the interface was shown in Fig. 10(a). Artifact was generated as shown by the arrows. Position registration of dentition between CT jawbone image and cast was done as shown in Fig. 10(b). Dentition of CT image with artifact was replaced with that of cast image as shown in Fig. 10(c). The dentition in the bone image without artifact and with high accuracy could be reproduced, and this image was used for accurate surgical guide fabrication.

Implant simulation by using the commercial software (10DR) was shown in Fig. 11(a). Positional data of the inserted implant was sent to dental laboratory. They were introduced in the CT bone image, and surgical guide was designed by CAD using PHANTOM as shown in Fig. 11(b). The surgical guides fabricated by RP equipment was shown in Fig. 12(a).

In this case, to support accurate insertion for the flapless operation, five surgical guides, one for the gums punch and four for the bone hole enlargement were fabricated. At the initial stage of clinical case-1, our technology was under development, and only one guide for the first drill could be fabricated, and the following hole enlargement was done by the free hand. In that case there was no problem because operator was an experienced, and the case was easy with enough amount of bone. At present, our system is supporting an accurate hole enlargement with multiple guides. Especially, the accurate position guide is required in the case of flapless operation, and multiple guides will be effective.

The photograph in the operation was shown in Fig. 12(b). In this case the immediate loading with provisional restoration was intended. Then, the implant analogues were inserted in the cast using the surgical guide as shown in Fig. 13(a), and the temporary cylinders were installed as shown in Fig. 13(b), and provisional restorations were fabricated as shown in Fig. 13(c). They could be set accurately in the patient just after the implant surgery as shown in Fig. 13(d). It was done successfully without adjustment, and the whole operation from surgery to provisional installation could be completed about 50 min [9,10]. After a few months final restorations with zirconia abutment were CAD/CAM fabricated as shown in Fig. 13(e), and they were applied on the implants of the patient as shown in Fig. 13(f).

This case can be accounted as the most up-to-date example by immediate loading with flapless surgery. In addition to this case, our "BoneNavi" system is possible to treat other various operational methods like the flap operation to put the guide on

Figure 12 (a) Fabricated multiple surgical guides. One for the gum punch and four for the bone hole enlargement; (b and c) flapless surgical operation with teeth supported surgical guide; and (d) dental X-ray photograph of implants placed on the right molars.

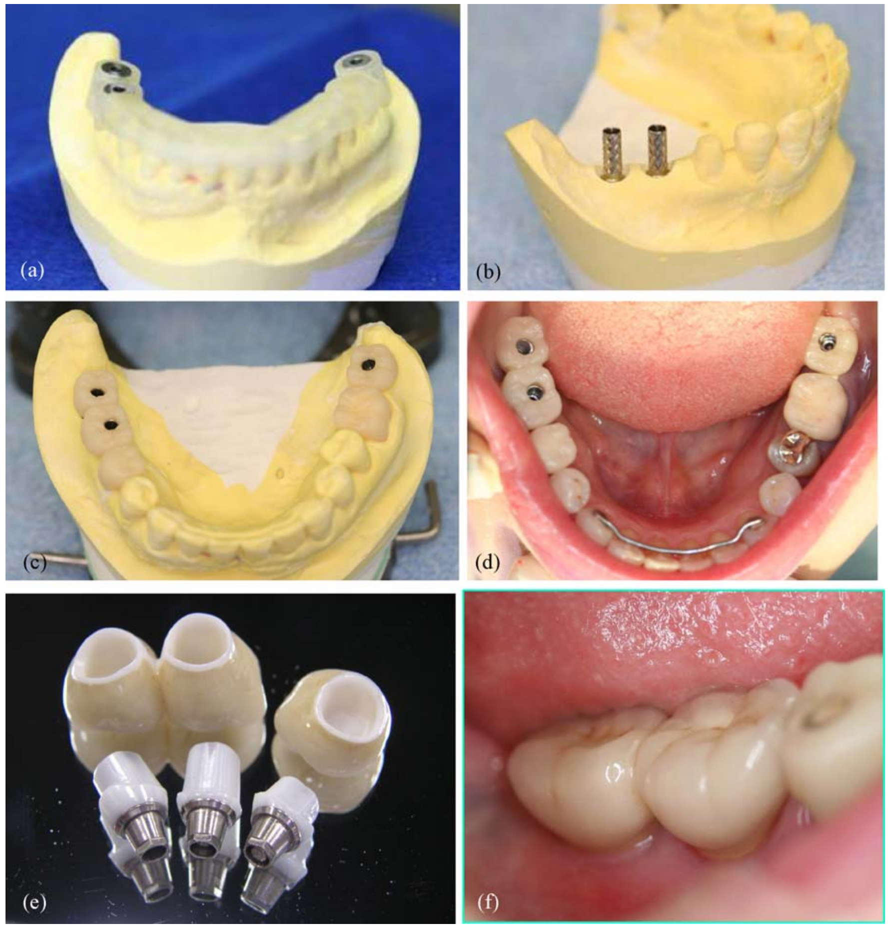

Figure 13 Fabrication of provisional restoration for immediate loading. (a) Implant analogues were placed in the cast using the surgical guide; (b) temporary cylinders were installed; (c) provisional restorations was fabricated; (d) accurate installation in the oral of the patient just after the implant surgery; (e) CAD/CAM fabrication of the final restorations of zirconia abutment and crown; (f) application of final restorations.

the bone and dentition, and flapless operation to put the guide on the mucosa. Furthermore, our system is possible to apply generally for many implant systems delivered in our country.

4. Conclusion

The number of implants inserted domestically shows a big growth rate of 20% a year now.

The cases of the implant remedy will increase further as one of the dental treatments with higher satisfaction. Accordingly, the number of severe cases will be increased. We intend to improve our ''BoneNavi'' system further to offer a safer and more accurate implant operation to both the patients and dentists.

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