Article category: Case report

Title: Newly developed data-matching methodology for oral implant surgery allowing the automatic deletion of metal artifacts in 3D-CT images using new reference markers: A case report.

Abbreviated title: A newly developed, modified single CT scan method

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Key words: computer-assisted surgery, computer-aided design, Tomography, guided surgery, artifact

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Abstract

Patients: The patient was a 55-year-old woman with left upper molar free-end edentulism and 9 full cast metal crowns in her mouth. Three three-dimensional (3D) images were superimposed: a computed tomography (CT) image with the patient wearing the CT-matching template (CTMT) with six glass ceramic markers, which hardly generate any artifacts, on the template surface, and oral plaster model surfaces with and without CTMTs. Metal artifacts were automatically removed by a Boolean operation identifying unrealistic images outside the oral plaster model surface. After the preoperative simulation, fully guided oral implant surgery was performed. Two implant bodies were placed in the left upper edentulism. The placement errors calculated by comparing the preoperative simulation and actual implant placement were then assessed by a software program using the 3D-CT bone morphology as a reference. The 3D deviations between the preoperative simulation and actual placement at the entry of the implant body were a maximum 0.48 mm and minimum 0.26 mm. Those at the tip of the implant body were a maximum 0.56 mm and a minimum 0.25 mm.

Discussion: In this case, the maximum 3D deviations at the entry and tip section were less than in previous studies using double CT.

Conclusions: Accurate image fusion utilizing CTMT with new reference markers was possible for a patient with many metal restorations. Using a surgical guide manufactured by the new matching methodology (modified single CT scan method), implant placement deviation can be minimized in patients with many metal restorations.

Key words: computer-assisted surgery, computer-aided design, Tomography, X-Ray Computed, artifact

Main Text

1. Introduction

A surgical guide is useful for the performance of ideally-designed top-down treatment in oral implant surgery, with the avoidance of any damage to anatomical structures such as vessels, nerves, and the sinus.

Currently, a single computed tomography (CT) scan method [1-4] is widely used to manufacture surgical guides. In order to accurately reflect the preoperative simulation in the surgical guide manufacturing process, a highly accurate overlapping three-dimensional (3D) CT imaging technique (digital imaging and communications in medicine; DICOM data) and 3D oral plaster model surface images (stereolithography; STL data) are necessary [1-3,5]. In the conventional single CT scan method, the surfaces of the artificial teeth of the diagnostic mock-up are used as a reference to fuse the DICOM and STL data. However, metal artifacts in 3D CT images of patients with metal restorations frequently appear in the diagnostic mock-up zone, which thus reduce the matching points and significantly affect the matching accuracy. In addition, the presence of artifacts can conceal the anatomical 3D structures of the soft and hard tissues, which may adversely impact diagnostic accuracy [3].

In such cases, a double CT scan method [6-8] using two types of CT images (DICOM data): a 3D CT image obtained with the patient wearing a denture and a 3D CT image of the denture is often utilized. In this method, the 3D DICOM data from the two images are fused with simultaneously taken images of reference markers located in the denture vestibule. By this method, 3D image fusion can be performed, even in the presence of artifacts. However, dimensional errors due to deformation of the radiographic guide and marker artifacts (known as pseudo image formation) will not be negligible in some clinical settings, since the resolution of 3D DICOM data is less than that of the 3D surface STL data [3,9-11].

In order to solve these problems and enable guided surgery in patients with many metal restorations, a modified single CT scan method described in this article has been established. In this method, three 3D images are superimposed: 1) a CT image (DICOM data) with the patient wearing a CT matching template (CTMT) with 6 glass ceramic reference markers, which hardly generate artifacts [12], located on the template surface; 2) a surface image (STL data) of the patient's oral plaster model without a CTMT; and 3) the STL data with a CTMT. Metal artifacts are automatically removed by a Boolean operation. This new method will be introduced in a case with many metal restorations.

2. Outline of the case

2. 1. Patient profile

The patient was a 55-year-old woman who complained of masticatory disturbance and decided to undergo oral implant treatment in February 2017. She had a free-end saddle missing at her left maxillary molar region and 9 full cast metal crowns out of 12 existing maxillary teeth (Fig. 1a). Six of those were porcelain fused to cast crowns, and three were full cast crowns. A dental panoramic X-ray image revealed that cast core and prefabricated post core restorations were installed under all of the restored teeth (Fig. 1b). Thus, extensive metal artifacts would be generated when CT images were obtained and it would be difficult to accurately fuse the DICOM data to the STL data of the oral plaster model using the conventional single CT scan method [3,13]. The Smart Fusion (Nobel Biocare, Switzerland) methodology was attempted, without any successful matching result in this case. We therefore decided to perform oral implant surgery using a surgical guide fabricated by a modified single CT scan method with newly developed reference markers. The patient was informed of the purpose of the study, and her informed consent was obtained before the study onset.

2. 2. Manufacturing the CT matching template (CTMT)

An oral plaster model of the patient's upper jaw was produced by a silicone impression technique, and the 3D surface morphology was digitized using a 3D desktop lab scanner (CARES Scanner D7 plus, Dental Wings Inc., Canada). Subsequently, a resin (SHERAprint-sg, SHERA Werkstoff Technologie GmbH & Co., Germany) base template was fabricated using a 3D printer (CARES P series, Rapid Shape GmbH, Germany), and 6 reference markers were attached to the top of the occlusal surface. The template was called a CT-matching template (CTMT). The reference markers were made of glass ceramics (Straumann N!ce Fully Crystallized glass-ceramic, Straumann Co., Switzerland) [12] which hardly generate artifacts in the 3D CT image.

The location of the reference markers was far enough from the alveolar bone or teeth to avoid the influence of metal artifacts, as well as scattering, beam hardening and imaging volume size effects caused by the restored teeth and alveolar bone (Fig. 2).

2. 3. Matching workflow using CTMT

A 3D CT scan (Aquilion Lightning, CANON MEDICAL SYSTEMS, Japan) was performed with the patient wearing a CTMT. The DICOM data acquired from the 3D CT scan was transferred to an implant planning software program (coDiagnostiX, Dental Wings Inc., Canada), and the threshold to generate the 3D CT scan image was set to a predetermined value so that the size and shape of the reference marker would be accurately reproduced (Fig. 3a). In addition, two sets of STL data of the oral surface morphology were acquired by scanning oral plaster models with and without a CTMT using a 3D desktop lab scanner. Then, the STL data of the oral plaster model with the CTMT was read by the planning software program, and the 3D oral surface image and previously imported 3D CT image were superimposed using the reference markers. At that time, it was confirmed that the hemispherical depression cut out from the upper face of the cubical block and the side flat face of the reference markers was well-matched in both images (Fig. 3b). Next, the STL data of the oral plaster model without CTMT was read in the planning software program, and the 3D oral surface images and the 3D oral surface images with CTMT were superimposed by referencing the edge shape of the plaster model (Fig. 3c). As a result, the patient's dentition and bone information obtained from the DICOM data of the 3D CT scan and the patient's dentition and soft tissue information obtained from the STL data of the oral plaster model surface morphology were matched accurately (Fig. 3d).

2. 4. Automatic deletion of metal artifacts and surgical guide design

The DICOM data of the 3D CT image was read by the planning software program, the imaging threshold of which was set to the bone morphology, which could be accurately expressed (Fig. 4a). Then, the 3D CT image was overlapped onto the 3D oral surface image (Fig. 4b) and the metal artifacts outside of the 3D oral surface image derived from the oral plaster model were automatically deleted by a Boolean operation (Fig. 4c). By this operation, the anatomical structure of the maxilla and teeth—which had been invisible due to metal artifacts—became clear. This method could reproduce not only the patient’s hard tissues but also soft tissues (Fig. 5a), where the preoperative simulation could be performed using 3D CT images (Fig. 5b, c, d).

2. 5. Treatment steps

A surgical guide was manufactured from the preoperative simulation data using the 3D CT images (Fig. 6a). In November 2017, two implant bodies (BLT implant, Φ 4.1 mm × 10 mm, Straumann Co., Switzerland) were placed in the left upper first molar and the second molar region (Fig. 6b). In April 2018, an implant superstructure was successfully installed (Fig. 6c, d).

2. 6. Preoperative simulation and actual placement of the implant bodies

The DICOM data of the preoperative and postoperative CT scan images were read by the planning software program (coDiagnostiX, Dental Wings Inc., Canada). The preoperative and postoperative DICOM data were adjusted to the same CT threshold and the two sets of data were then automatically accurately super-imposed with reference to the characteristic anatomical morphology of the CT images by a software function (Fig. 7a, b). The preoperative simulated image was then super-imposed on the postoperative CT images (Fig. 7c, d) and the 3D positional deviations, distances, and angulations between the preoperative simulation and the actual placement of the implant bodies were measured automatically using the “Treatment Evaluation” function. Specifically, the X deviation (mesio-distal axis), Y deviation (the buccal-lingual axis) and Z deviation (the depth axis) were automatically measured in the position of the entry and tip of the planned and placed implant bodies, and the 3D deviation ($3D=\sqrt{X^2+Y^2+Z^2}$) was calculated. In addition, the 3D angulation shifts were automatically measured as the difference in angle between the long axes of both implant bodies.

2. 7. Preoperative simulation and actual placement of the implant bodies

In the two placed implants, the positional deviation of the implant between the preoperative simulation and the actual placement were measured using the planning software program. As a result, the 3D deviation in the entry of the implant body was measured as 0.48 (#26) and 0.26 (#27) mm, and that in the tip of the implant body was 0.56 (#26) and 0.25 (#27) mm. The 3D angulation shift was measured as 2.00° (#26) and 1.20° (#27).

3. Discussion

The patient had so many metal restorations that a conventional single CT scan method could not match the data from the 3D CT image (DICOM data) and the 3D oral plaster model surface images (STL data). Meanwhile, the modified single CT scan method introduced here enabled the accurate matching of these images using glass ceramic reference markers. Moreover, the method enabled the automatic deletion of metal artifacts by a Boolean operation. According to a previous systematic review [14], when oral implant placement was performed using a conventional single CT scan method, the mean deviation in the entry section of the implant body was 0.99 mm (6.50 mm at maximum) and that in the tip of the implant body was 1.24 mm (6.90 mm at maximum). It was also suggested that the average angle shift of the implant body was 3.81° (24.9° at maximum). Furthermore, according to several previous articles [15-18], when oral implant placement was performed using a double CT scan method, the mean deviation in the entry section of the implant body was 1.37 mm at the minimum and 1.97 mm at the maximum, and that in the tip of the implant body was 1.58 mm at the minimum and 2.29 mm at the maximum. It was also suggested that the average angle shift of the implant body was 2.44° at the minimum and 3.93° at the maximum.

In the present case, the maximum 3D deviation in the entry section, the maximum 3D deviation in the tip section and the maximum angle shift of the implant bodies was 0.48 mm, 0.56 mm and 2.00°, respectively, which was substantially less than those values reported in the review[14] and previous articles on double CT scan methods [15-18]. To strengthen the generalizability of the methodology, the 3D CT images should be clearly described using either a medical CT device or a cone beam CT device. In addition, the 3D desktop lab scanner can also be replaced by an intra oral scanner for the surface digitization of the plaster model with and without CTMT. However, a 3D scanner is not required when applying the double CT scan method, although it is indispensable for the modified single CT scan method.

Based on the experience in this case, it was strongly suggested that the modified single CT scan method introduced in this report provided a very attractive digital workflow to overcome metal and marker artifacts in patients with many metal restorations.

4. Conclusion

Accurate image fusion utilizing CTMT with new reference markers was possible for a patient with many metal restorations. Using a surgical guide manufactured by the modified single CT scan method, implant placement deviation can be minimized in patients with many metal restorations.

Conflict of interest statement

First author holds patents (P6238330) on the newly developed reference marker and the matching workflow.

References

[1] Gateno J, Xia J, Teichgraeber JF, Rosen A. A new technique for the creation of a computerized composite skull model. J Oral Maxillofac Surg 2003;61:222–7. https://doi.org/10.1053/joms.2003.50033.

[2] Kernen F, Benic GI, Payer M, Schär A, Müller-Gerbl M, Filippi A, et al. Accuracy of three-dimensional printed templates for guided implant placement based on matching a surface scan with CBCT. Clin Implant Dent Relat Res 2016;18:762-8. https://doi.org/10.1111/cid.12348.

[3] Flügge T, Derksen W, Te Poel J, Hassan B, Nelson K, Wismeijer D. Registration of cone beam computed tomography data and oral surface scans– A prerequisite for guided implant surgery with CAD/CAM drilling guides. Clin Oral Implants Res 2017;28:1113-8. https://doi.org/10.1111/clr.12925.

[4] Flugge TV, Nelson K, Schmelzeisen R, Metzger MC. Three-dimensional plotting and printing of an implant drilling guide: simplifying guided implant surgery. J Oral Maxillofac Surg 2013;71:1340–6. https://doi.org/10.1016/j.joms.2013.04.010.

[5] van Steenberghe D, Naert I, Andersson M, Brajnovic I, Van Cleynenbreugel J, Suetens P. A custom template and definitive prosthesis allowing immediate implant loading in the maxilla: a clinical report. Int J Oral Maxillofac Implants 2002;17:663–70.

[6] Behneke A, Burwinkel M, Behneke N. Factors influencing transfer accuracy of cone beam CT-derived template-based implant placement. Clin Oral Implants Res 2012;23:416–23. https://doi.org/10.1111/j.1600-0501.2011.02337.x.

[7] Swennen GR, Barth EL, Eulzer C, Schutyser F. The use of a new 3D splint and double CT scan procedure to obtain an accurate anatomic virtual augmented model

of the skull. Int J Oral Maxillofac Surg 2007;36:146–52. https://doi.org/10.1016/j.ijom.2006.09.019.

[8] Katsoulis J, Pazera P, Mericske-Stern R. Prosthetically driven, computer-guided implant planning for the edentulous maxilla: a model study. Clin Implant Dent Relat Res 2009;11:238–45. https://doi.org/10.1111/j.1708-8208.2008.00110.x.

[9] Fortin T, Bosson JL, Coudert JL, Isidori M. Reliability of preoperative planning of an image-guided system for oral implant placement based on 3-dimensional images: an in vivo study. Int J Oral Maxillofac Implants 2003;18:886–93. https://doi.org/10.1016/j.prosdent.2004.03.017.

[10] Di Giacomo GA, Cury PR, de Araujo NS, Sendyk WR, Sendyk CL. Clinical application of stereolithographic surgical guides for implant placement: preliminary results. J Periodontol 2005;76:503–7. https://doi.org/10.1902/jop.2005.76.4.503.

[11] Stumpel LJ. Deformation of stereolithographically produced surgical guides: An observational case series report. Clin Implant Dent Relat Res 2012;14:442-53. https://doi.org/10.1111/j.1708-8208.2010.00268.x.

[12] Rodrigues SP, Paiva JM, De Francesco S, Amaral MI, Oliveira FJ, Silva RF. Artifact level produced by different femoral head prostheses in CT imaging: diamond coated silicon nitride as total hip replacement material. J Mater Sci Mater Med 2013;24:231-9. https://doi.org/10.1007/s10856-012-4778-0.

[13] Vasconcelos TV, Bechara BB, McMahan CA, Freitas DQ, Noujeim M. Evaluation of artifacts generated by zirconium implants in cone-beam computed tomography images. Oral Surg Oral Med Oral Pathol Oral Radiol 2017;123:265-72. https://doi.org/10.1016/j.oooo.2016.10.021.

［14］ Van Assche N, Vercruyssen M, Coucke W, Teughels W, Jacobs R, Quirynen M. Accuracy of computer-aided implant placement. Clin Oral Implants Res 2012;23:112-23. https://doi.org/10.1111/j.1600-0501.2012.02552.x.

［15］ Vasak C, Watzak G, Gahleitner A, Strbac G, Schemper M, Zechner W. Computed tomography-based evaluation of template (NoobelGuide™)-guided implant positions; a prospective radiological study. Clin Oral Implants Res 2011;22:1157-63. https://doi.org/10.1111/j.1600-0501.2010.02070.x.

［16］ Verhamme LM, Meijer GJ, Bergé SJ, Soehardi RA, Xi T, de Haan AF, et al. An accuracy study of computer-planned implant placement in the augmented maxilla using mucosa-supported surgical templates. Clin Implant Dent Relat Res 2015;17:1154-63. https://doi.org/10.1111/cid.12230.

［17］ Verhamme LM, Meijer GJ, Boumans T, de Haan AF, Bergé SJ, Maal TJ. Clinically relevant accuracy study of computer-planned implant placement in the edentulous maxilla using mucosa-supported surgical templates. Clin Implant Dent Relat Res 2015;17:343-52. https://doi.org/10.1111/cid.12112.

［18］ Verhamme LM, Meijer GJ, Boumans T, Schutyser F, Bergé SJ, Maal TJ. A clinically relevant validation method for implant placement after virtual planning. Clin Oral Implants Res 2013;24:1265-72. https://doi.org/10.1111/j.1600-0501.2012.02565.x.

Figure legends

Fig. 1: An intraoral photograph and dental panoramic X-ray image obtained at the patient's first visit

a: Maxillary occlusal view

b: Dental panoramic X-ray image

Fig. 2: The CT matching template (CTMT) attached to the patient's oral plaster model

Fig. 3: Matching a 3D CT image with 3D oral surface images referencing the new markers

a: A 3D CT image of the patient's maxilla with the CTMT (left view) and a 3D oral surface image with the CTMT (right view)

b: The super-imposed image (a left and a right) of the right maxillary second molar (at the red reference marker). The red line shows an outline of the frontal section of the 3D oral surface image with the CTMT.

c: A 3D oral surface image with the CTMT (left view) and a 3D oral surface image without the CTMT (right view)

d: The super-imposed image (c left and c right) of the right maxillary second molar. The green line shows the outline of the frontal section of the 3D oral surface image without the CTMT.

Fig. 4: The process of the automatic deletion of metal artifacts.

a: 3D CT images with the CTMT

b: 3D CT images with the CTMT and the 3D oral surface image c: 3D CT images and the 3D oral surface image after the automatic elimination of metal artifacts

Fig. 5: Preoperative simulation.

a: The superimposed image of the 3D CT image and the 3D oral surface images after the elimination of artifacts by synergy link between CARES® and coDiagnostix® and a diagnostic wax-up procedure.

b: Determination of the implant placement positions on the superimposed image

c: The positional relationship between the implant body and the adjacent tooth roots on the matching image

d: The surgical guide fabricated for guided surgery

Fig. 6: Intraoral photographs and a dental panoramic X-ray image after implantation and installation of the implant superstructure.

a: The surgical guide.

b: An intraoral photograph immediately after implant surgery

c: An oral photograph after the installation of the superstructure

d: A dental panoramic X-ray image after the installation of the superstructure

Fig. 7: The preoperative simulation and actual placement of the implant bodies

a: Anatomical landmarks on preoperative and postoperative 3D CT images

b: Superimposed preoperative and postoperative images

c: Left upper first molar tooth region

d: Left upper second molar tooth region

The blue line shows the position of the simulated implant position, and the red line shows the actual placement position.

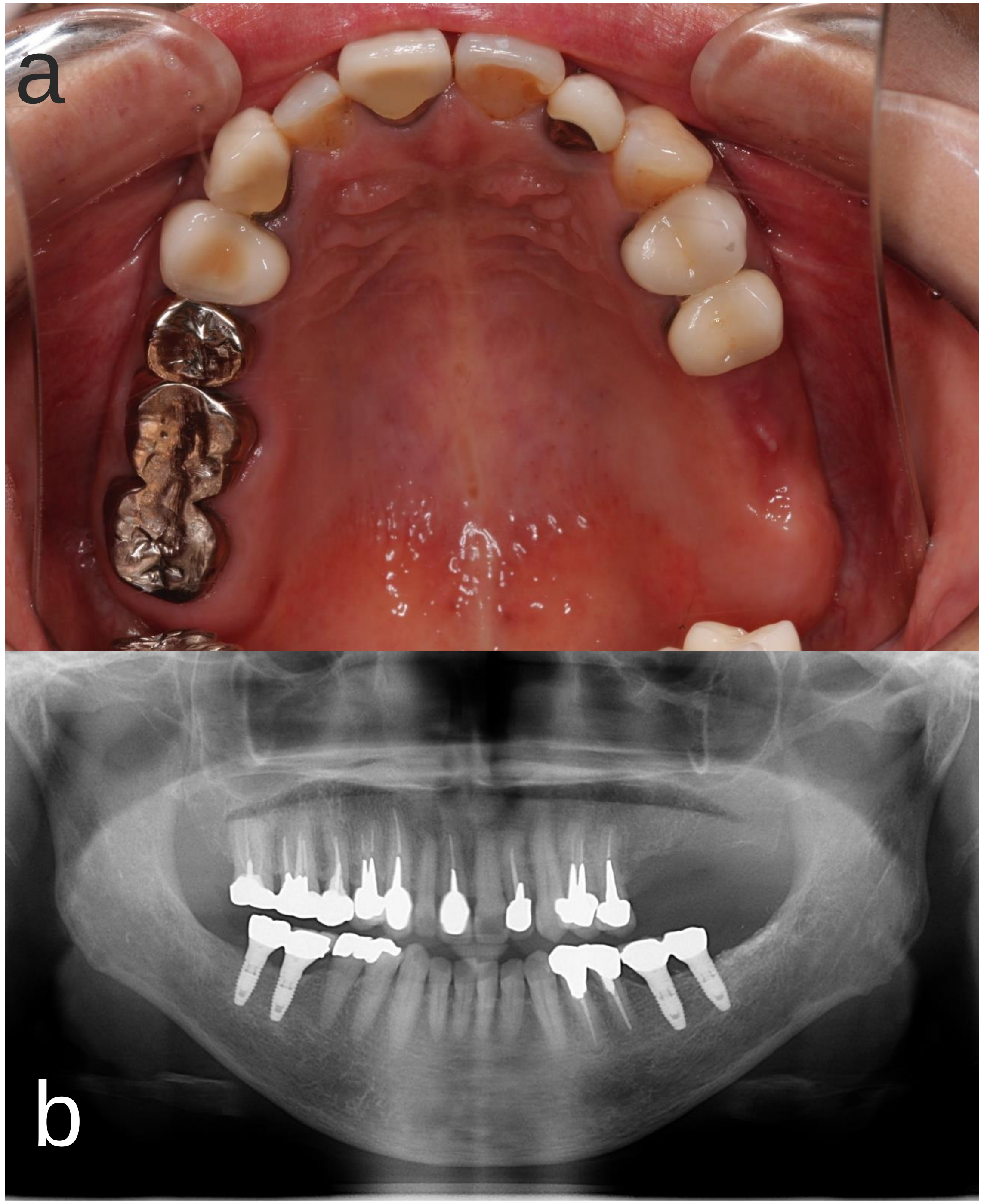
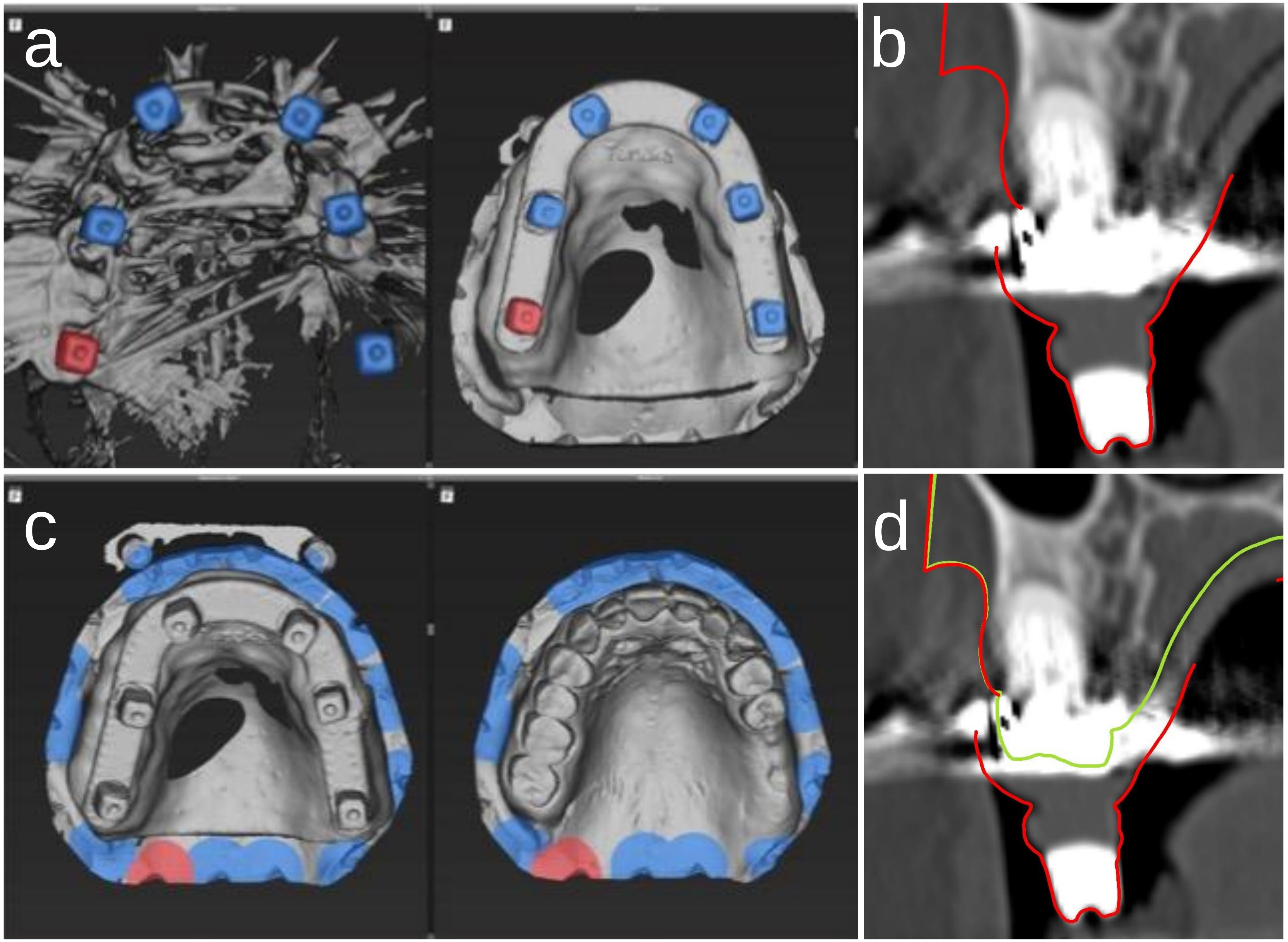


Fig. 1

Fig. 2



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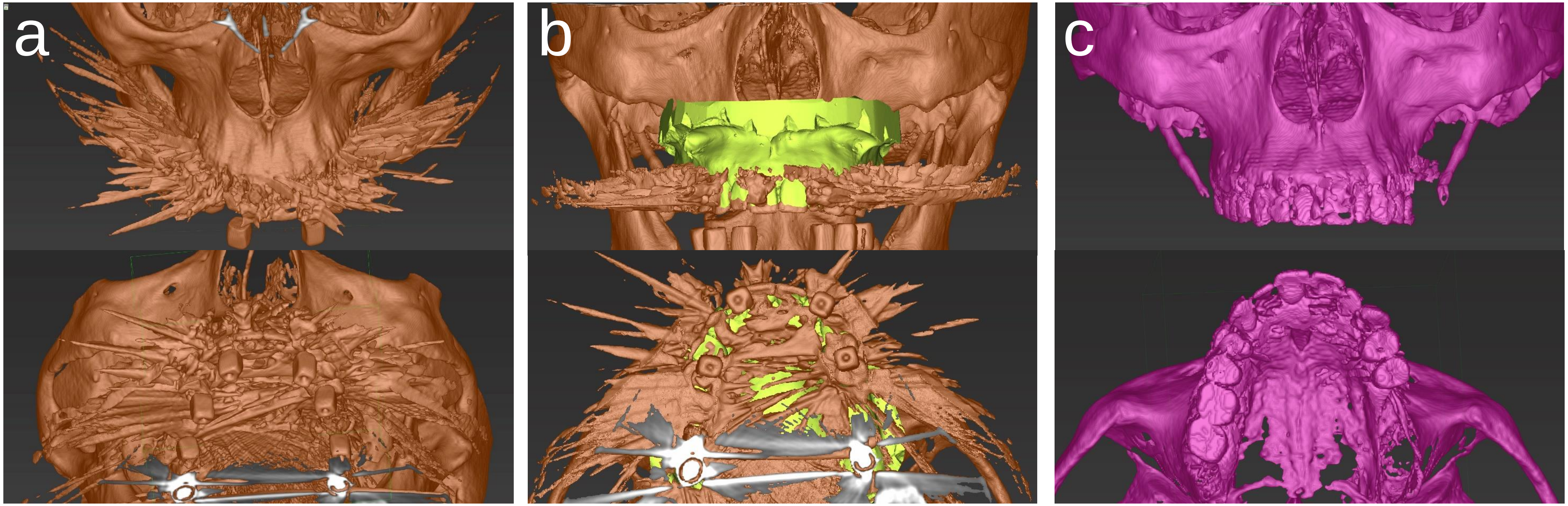
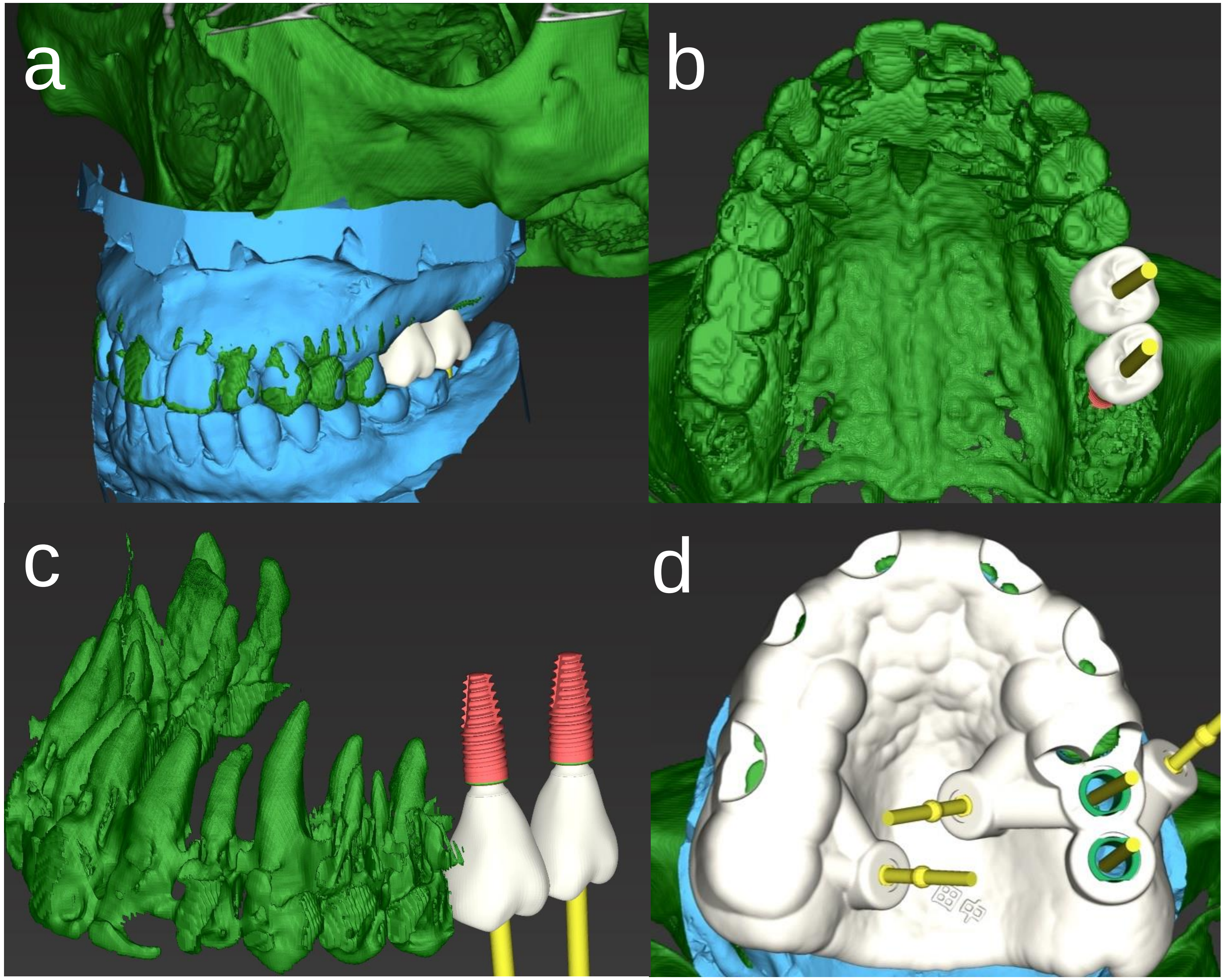


Fig. 4



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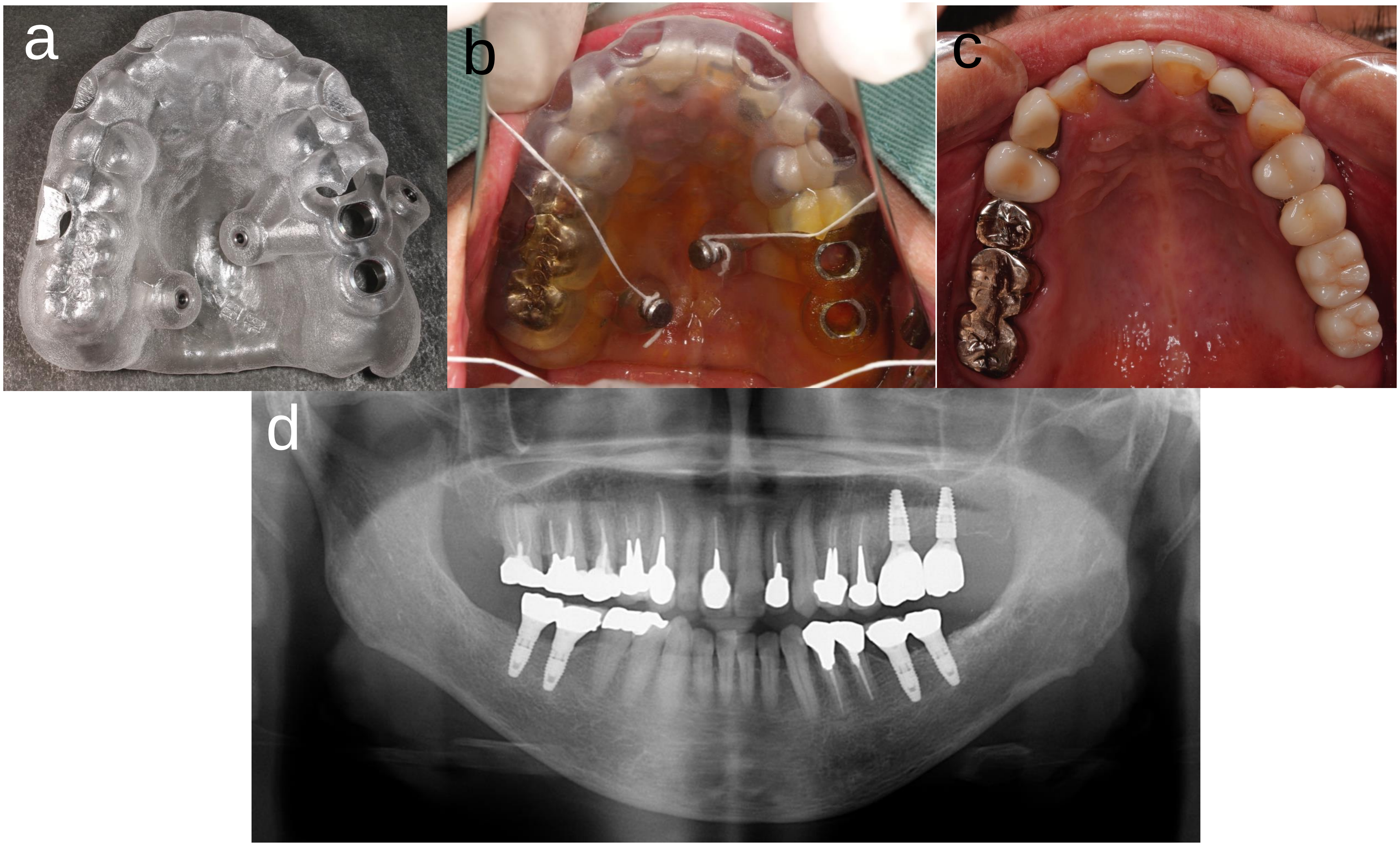

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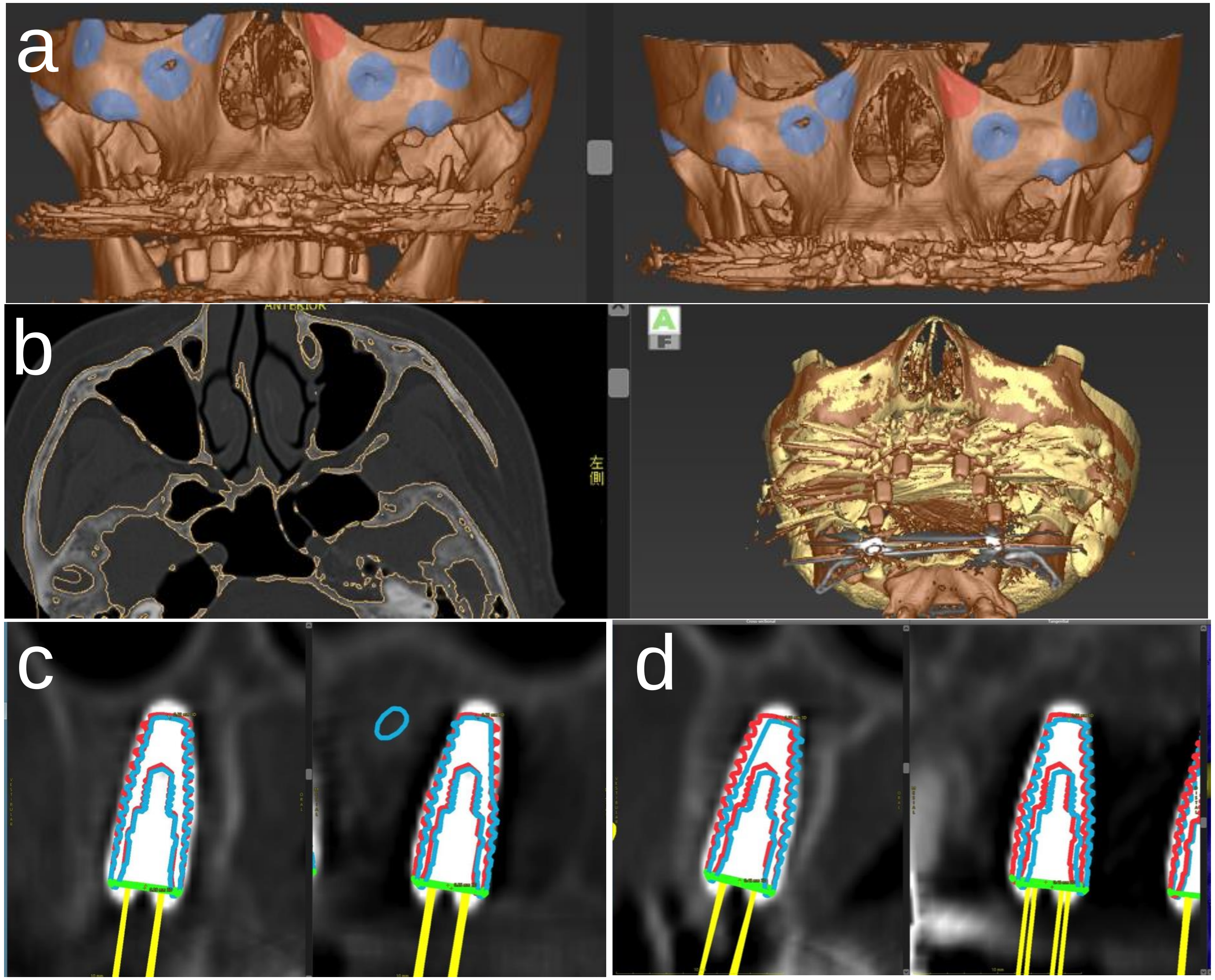

Fig.7