A Fast, Accurate and Easy Method to Position Oral Implant Using Computed Tomography
Clinical Validations

Guillaume Champleboux[1], Thomas Fortin[2], H. Buatois[3]
Jean Loup Coudert[2], Eric Blanchet[1]
[1] TIMC-IMAG, IAB - Faculté de Médecine de Grenoble
38700 La Tronche, France. Email: Guillaume.Champleboux@imag.fr
[2] Faculté d'Odontologie de Lyon, 69008 Lyon, France
[3] 41 Av. Alsace-Lorraine, 38000 Grenoble, France.

Abstract

This paper presents a simple method and new material which allow transferring results of surgical planning - such as the implant fixture axis - to the surgical site. This method is based on drilling a linear guide in a resin splint corresponding to the fixture axis. A simple mechanical setup links the Computed Tomography (CT) data set with the drilling machine. Since the optimal fixture axis is determined with a software interface, it can be transferred as a linear guide to the resin splint with the drilling machine. Technical validation demonstrates that the accuracy of the method is 0.2 mm in translation and 1 degree in rotation. These results provide a high level of accuracy and clinical validation has begun with several patients. The results for the patients are very satisfactory.

1 Introduction

The objective of a surgical procedure in oral implant treatment is to place a fixture on the jaw bone according to several prosthetic criteria of success such as phonation, appearance and masticatory functions. Computed tomography is used more and more for dental implant surgery planning in order to meet the above criteria of success. The standard method for determining the fixture axis using CT Images consists of the following steps:
- Determination of the prosthesis suprastructure position with a diagnostic cast of the maxilla and mandible.
- CT image acquisition with the materialized prosthesis axis.
- CT-based planning for the fixture axis.

This last step allows taking into account the dimension of the anatomical volume, jaw bone quality, and avoids damaging structures such as dental nerve and sinus. The result is a compromise between the prosthesis axis (materialized) and the ideal axis (computerized) hereby referred to as the optimal axis.
For more details see [1], [2], [3], [4], [5], [6], [7], [8], [9]. the main problem is now to **transfer** the information from the surgical plan to the surgical site.

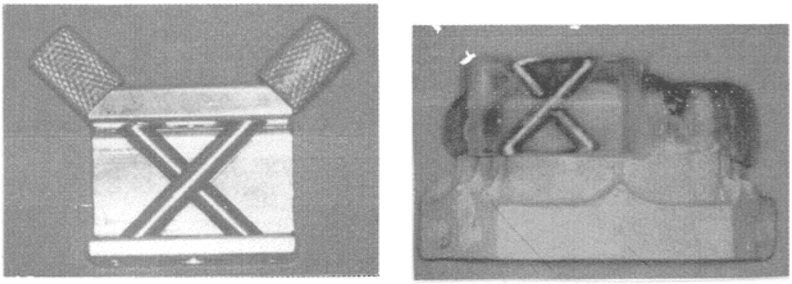
In this paper a simple and accurate method to place one or several oral implants is briefly decribed (see [10] for more details and an explanation of the principles and methodology of the system. This will be followed by a description of the technical validation of the system. Finally, we conclude with a detailed presentation of the first clinical validation on two patients.

2 Transfer of the optimal axis to the surgical site

Presentation
To our knowledge there is at present no common simple system which allows the transfer of scanner information, i.e., the coordinates of the optimal axis, to the surgical site. After the evaluation of the optimal axis, the clinician has to mentally integrate the geometry of the mouth with the CT scans through the area, and transfer it to the surgical site without any encoded reference. Various solutions have been developed:
- Fortin et al.[3] used a guide drilled into a resin splint to accurately place the implant in the planned position. The guide was drilled thanks to computed planning and a 3D localizer.
- Solar et al.[11] propose an image-guided drill positioning system. These solutions require sophisticated hardware.
- Bauer et al. [12] propose a two parts device made of a holder and a drilling duct to be fixed upon the holder. The holder contains radiopaque markers which link the Scanner with the setup (holder-drilling duct). After the determination of the implant axis thanks to CT images, the drilling duct is therefore processed by stereolithography. The referenced paper do not describe either surgical planning or clinical validation.

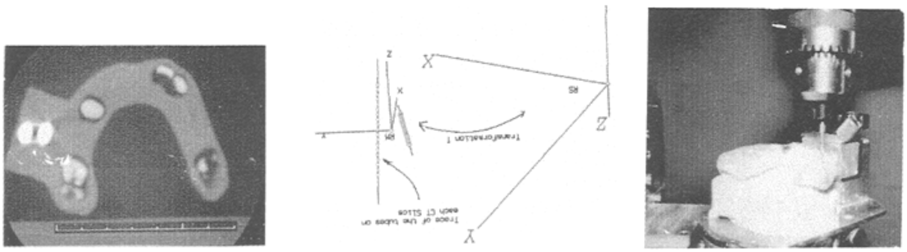
Description of the method
The method described herein was reported in [10] and also uses a guide made into a resin splint. The basis is a drilling machine whose configuration can be tuned with 4 degrees of freedom (dof), because an axis in space has 4 dof. To drill the guide it is of primary importance to find a rigid transformation T between the reference coordinate system (RCS) of the scanner R_S - in which the optimal axis is defined - and the RCS of the drilling machine (noted as R_M).

Finding the transformation T between the two RCS.
A mechanical device was built which allows fixing two tubes made of titanium in a defined position. Because these two tubes (called linker tubes) can be linked easily to the drilling machine, the RCS of the drilling machine will be **visible** in the 3D CT data set (see Fig. 1a). It associates the resin splint to a removable mechanical support and provides for removable links which preserve the respective position of the splint and the mechanical support when they are associated. Fixing the two tubes during the molding of the resin splint requires no more than surrounding the tubes with resin inside the device. Once the resin is solid, the separation between the splint and the device is achieved by removing the two shafts (see Fig. 1b). While processing the CT Images containing the track of the tubes, it is possible to define a RCS which is the RCS of the mechanical device



(a) (b)

Fig. 1. *(a) Mechanical system for the fixation of the tubes in the resin splint. Device + two titanium tubes + two metallic shafts. (b) Fixation of the tubes in the resin splint*



(a) (b) (c)

Fig. 2. *(a) CT Image passing though the tubes. (b) The 3D representation showing the RCS of the scanner R_S, the track of the tubes and the RCS of the drilling machine R_M defined by the axes of the tubes. (c) The splint is fixed on the drilling machine and drilled following the fixture axis.*

in the RCS of the scanner, i.e., the transformation between the two essential RCSs is determined (see Fig. 2b).

Drilling the guide.
Once the surgical planning has been done, the resin splint is attached to the device with the two shafts. The whole system is then fixed on the plate of the drilling machine. The system was designed such that the reference RCS of the drilling machine coincides with that defined by the titanium tubes (see Fig. 2c). Currently, for drilling, the tune of the plate is done by hand

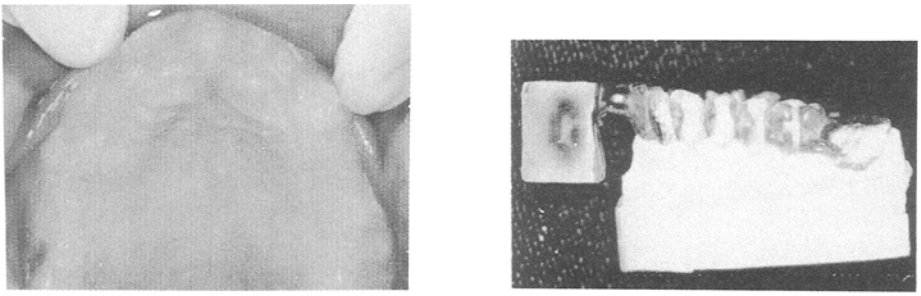
Technical validation.
Starting from a "master model" with several teeth missing, a plaster cast was molded. One or more titanium tubes (inner diameter 2mm, length 10 mm) were included in the plaster cast. A resin splint was then molded on the plaster cast with the mechanical system which allows the drilling machine the scanner to be linked. The axes of the implant are also determined with the software used for surgical planning. Validating this technique involved ascertaining whether the

axes determined with surgical planning using CT images were indeed reported on the resin splint. Every time the splint was drilled, the drill entered the titanium tube in the plaster cast. This result was valid for each of the 8 titanium tubes inserted in the 3 different plaster casts. In fact, a 1.8 mm diameter drill entered a 2.0 mm diameter titanium tube. Because the titanium tube is 10 mm long, the error is less than 0.2 mm in translation and less than 1.1 degrees in rotation.

3 Clinical validation

First patient

Presentation. The first case reported in this paper concerns a patient without teeth on the maxilla (see Fig. 3a). A prosthesis study was conducted to place teeth and implants according to the criteria of phonation, appearance and masticatory functions. This led to modeling the placement of teeth on the maxilla. During the molding of the resin splint radiopaque material was inserted in the splint in order to model the prosthesis axes associated with the nine planned teeth. The two linker tubes were added to the splint with the system described above (see Fig. 3b) and CT images of the patient were acquired with the splint in the mouth. The CT slices were 1 mm thick and spaced every millimeter.



(a) (b)

Fig. 3. *(a) The toothless maxilla of the first patient. (b) The molded resin splint on the cast with the linker tubes inserted. The prosthesis axes are also materialized in the splint*

Surgical planning with a software interface on a workstation. To place a virtual implant on the CT data set, two points must be clicked on two different slices in order to give the direction of the implant. This is done using the tracks of the radiopaque marker in two different slices; thus the initial direction of the virtual implant is known. Reformatted slices are also computed and displayed on the right side. These reformatted slices, both a pseudo-sagittal and a pseudo-frontal slice, allow the determination of the length and the width of the implant. The translation and rotation "push-buttons" are useful to tune the orientation and position of the virtual implant in order to take into account the position of the sinus and the structure of the bone. On the current CT image,

the projection of the implant on the plane defined by the CT slice is graphically represented, the perpendicular to the projection is also added. This shows the direction of the implant relative to the curve defined by the bone. When all the criteria are satisfactory, the features of the implant are saved and a new virtual implant can be planned (see Fig. 4).
The track of the later implants are already displayed in another color. This yields the position of an implant relative to the others. Once surgical planning is achieved, the resin splint is fixed on the plate of the drilling machine and drilled according to the several computed postions (see Fig. 5a). Then the two linker tubes are detached from the splint in order to have an adapted surgical guide. Some of the resin is also removed because gum has been cut from the bone and must not hide the bone. With the guide in the mouth the surgeon drills the bone taking into account the feature (diameter and length) of the implant to be positioned, and screws the implant in the drilled hole (see Fig. 5b).

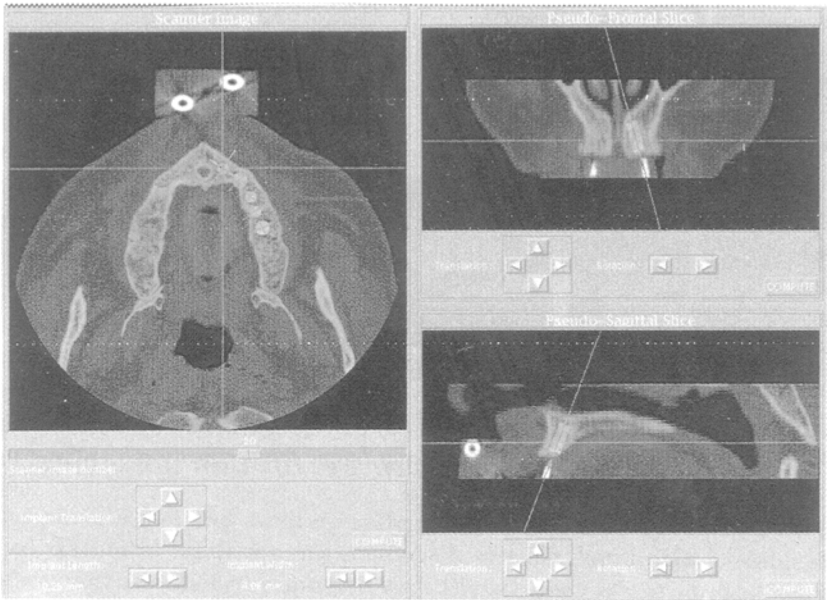
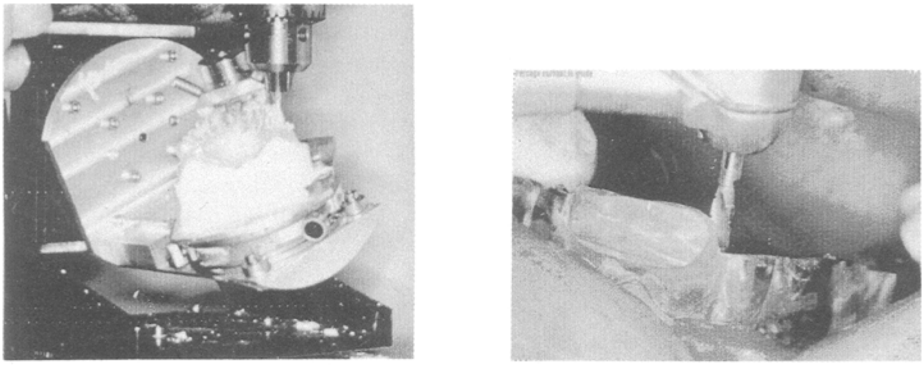


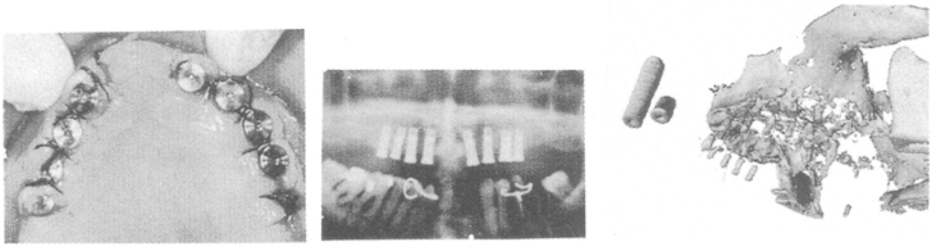
Fig. 4. *The display of the whole interface, current CT slice, tracks of virtual implant, reformatted slices and track of the current implant on these slices.*

Result and discussion. It was possible to fix only eight of the nine planned implants (see Fig. 6a). One failed due to the poor quality of the bone. The results were very good compared to the X-ray control image (see Fig. 6c). Netherthe-less, complete osteointegration must be attained followed by fixing the prosthesis on the implant before results can be declared fully satisfactory. Verification with another scanner was ruled out due to an excessive x-ray dose for the patient over a short period. 3D Images obtained by using marching cube algorithm on the



(a) (b)

Fig. 5. *(a) The splint is drilled according to the computed positions. (b) The bone is drilled with the guide.*



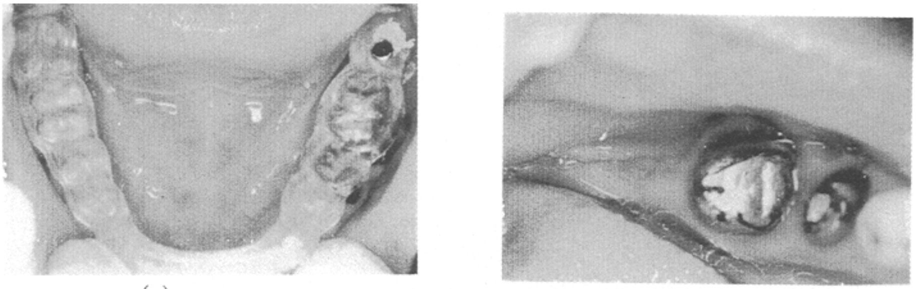
(a) (b) (c)

Fig. 6. *(a) The result for eight implants. (b) 3D reconstruction of the bone and the position and feature of the implants.(c) X-ray Image for verification.*

CT data set (see Fig. 6b). are a mean of verification. This tool of visualization must be developed in order to give the surgeon an other mean of work which is already the mental integration of 2D images.

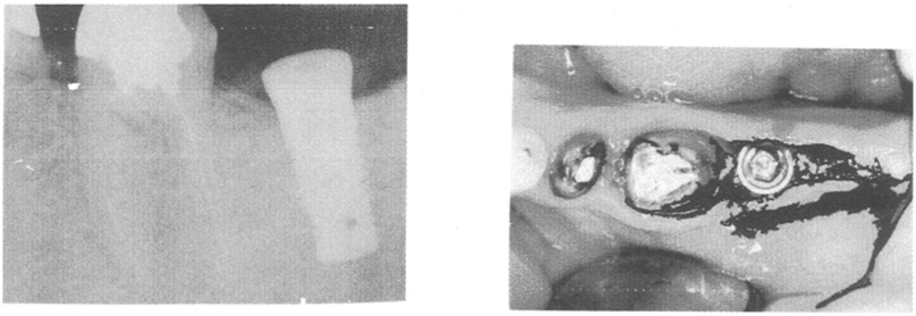
Second patient

The challenge was to place one implant in the posterior localisation of the mandible and to avoid the dental nerve. The steps described for the first patient were followed (see Fig. 7a, 7b, 8a, 8b). Result is very satisfacory. The same conclusion incoming osteointegration and fixation of the prosthesis on the implant remains valid. The the X-ray control image shows good parallelism of the implant and the previous teeth.



(a) (b)

Fig. 7. *(a) The splint in position in the mouth. (b) the site before the surgical act.*



(a) (b)

Fig. 8. *(a) X-ray Image for verification (patient 2). (b) The site after the surgical act.*

4 Conclusion and future work

In this paper a fast and accurate system to postion oral implants has been described. Technical validation was conducted, proving that despite possible errors high accuracy is obtained compared with the accuracy of the surgical act when it is done without the surgical guide. It is possible to place several oral implants with an accuracy of 0.2 mm. This technique is now being clinically validated. The use of this system for the first two patients (one with eight implants, the other with one implant) has given very good results (verification is done with an X-ray image). However, before fully satisfactory results can be declared, complete osteointergration must be awaited, followed by fixing the prosthesis on the implant. Using another scanner for verification was ruled out to minimize the patients'exposure to X-ray dose.

Clinical validation continues with a number of different cases. Currently The system has been used by 4 surgeons for 10 patients (34 implants) and results are very satisfactory. Parts of the software need to be improved. It will be possible in the future to recompute slices passing by any plane, i.e., not only the pseudo-sagittal and pseudo-frontal plane. The use of 3D reconstruction images must become easier in order to be able to display in real time and modify implants on these images.

References

1. Jeffcoat M.K. A Dental implant treatment planning tool for low-cost imaging workstations. In *Annual International conference of the IEEE Engineering in Medicine and Biology Society*, volume 13, pages 348–349, 1991.
2. Edge M.J. Surgical placement guide for use with osteointegrated implants. *Journal of Prosthet Dent.*, 57:719 – 722, 1987.
3. T. Fortin, J.L. Coudert, G. Champleboux, P. Sautot, and S. Lavallee. Computer-assisted dental implant surgery using computed tomography. *J. of Image Guided Surgery*, 1(1):53–58, 1995.
4. Bass S.L. The effects of preoperative resorption and jaw anatomy on implant success. A report of 303 cases. *Clin. Oral Impl. Res*, 2:193–198, 1991.
5. Jaffin A. and Berman C. The excessive loss of Branemark fixtures in type IV bone: a 5 analysis. *J. Periodontol.*, 62:2–4, 1991.
6. Weingart D., Hurzler M.B., and Knode H. Restoration of maxillary residual ridge atrophy using Le Fort I osteotomy with simultaneous endosseous implant placement: Technical Report. *Int. J. Oral Maxilofac. Implants*, 7:529–535, 1992.
7. Duyck J., Naert I.E., Van Oosterwyck H., Van der Sloten J., De Coomans M., Lievens S., and Puers B. Biomechanics of oral implant: a review of the literature. *Technology and Health Care*, 5:253–273, 1997.
8. Verstreken K., Van Cleynenbreugel J., Marchal G., Naert I., and Suetens P. Computer-Assisted Planning of Oral Implant Surgery: A Three Dimensional Approach. *Int J Oral Maxillofac. Implants*, 11:806–810, 1996.
9. Th. Fortin, J.L. Coudert, B. Francois, A. Huet, F. Niogret, M. Jourlin, and Ph. Gremillet. Marsupialization of dentigerous cyst associated with forein body using 3D CT images: a case report. *The Journal of Clinical Pediatric Dentistry*, 22(1):29 – 33, 1997.
10. Champleboux G., Blanchet E., Fortin Th., and Coudert J.L. A fast, accurate and easy method to position oral implants using computed tomography. In Lemke H.U., Vannier M.V., Inamura K., and Farman A.G., editors, *Computer Assisted Radiology.* Elsevier Science, 1998.
11. Solar P., Grampp S., Gsellmann B., Rodinger S., Ulm C., and Truppe M. A computer-aided navigation system for oral implant surgery using 3D-CT reconstruction and real time video-projection. In Lemke H.U., Vannier M.V., Inamura K., and Farman A.G., editors, *Computer Assisted Radiology*, pages 884–887. Elsevier Science, 1996.
12. J. Bauer, T. Kaus, T. Gruner, Th. Fleiter, R. Niemeier, and M. Schaich. CT-Data-Based Construction of a dental drilling device. In H.U. Lemke, editor, *CAR'96 (Computer Assisted Radiology)*, pages 958–963. Springer, 1995.