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DENTAL TECHNIQUE

An open protocol for evaluating the accuracy of guided implant surgery by using digital casts

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ABSTRACT

An open protocol is described for the evaluation of implant deviation by using digital casts. A digital surgical planning cast and a definitive cast are imported into a reverse engineering software program, and cylinders are created as simplifications of the implants. After superimposing the digital casts, implant deviations can be calculated by using the coordinates of the cylinders. This protocol only requires routine clinical data from the guided implant surgery and digital prosthodontic workflow; it can therefore be easily embedded into the clinical procedure. Any dental software program providing access to implant coordinates can be integrated with this protocol to overcome the shortcomings of various closed-loop workflows used by dental software programs. (J Prosthet Dent 2021;126:731-4)

Evaluating the accuracy of guided implant surgery is an important part of implant dentistry and essentially involves comparing an implant position after placement with its planned position. The 2 main approaches use either cone beam computed tomography (CBCT)[1-3] or digital definitive casts.[4,5] Using CBCT scans requires a postoperative CBCT scan, from which each implant is segmented. Superimposing the postoperative scan with the surgical planning scan determines the deviation of the implants, but additional radiation is required. Digital definitive cast analysis uses a conventional or digital definitive cast. The digital cast and implant platform interface are digitized by using an industrial coordinate measuring machine. The definitive cast is superimposed with the surgical planning cast for implant deviation analysis.[4] Some surgical planning software programs have built-in functions for implant analysis that can automatically calculate implant deviations by using an imported digital definitive cast with scan bodies after superimposing the digital definitive cast onto the surgical plan.[5] Although digital casts usually have a higher accuracy than CBCT scans,[6] their closed-loop workflows restrict a dentist's choice of devices and software programs.

The technique described removes the restrictions of these methods by developing a deviation calculation protocol for guided implant surgery, which is verified by using a commercially available dental computer-aided design (CAD) software package and 3D reverse engineering software program. The protocol features clear and accurate mathematical operations of computer graphics[7] and an open-loop workflow for integration with various software programs.

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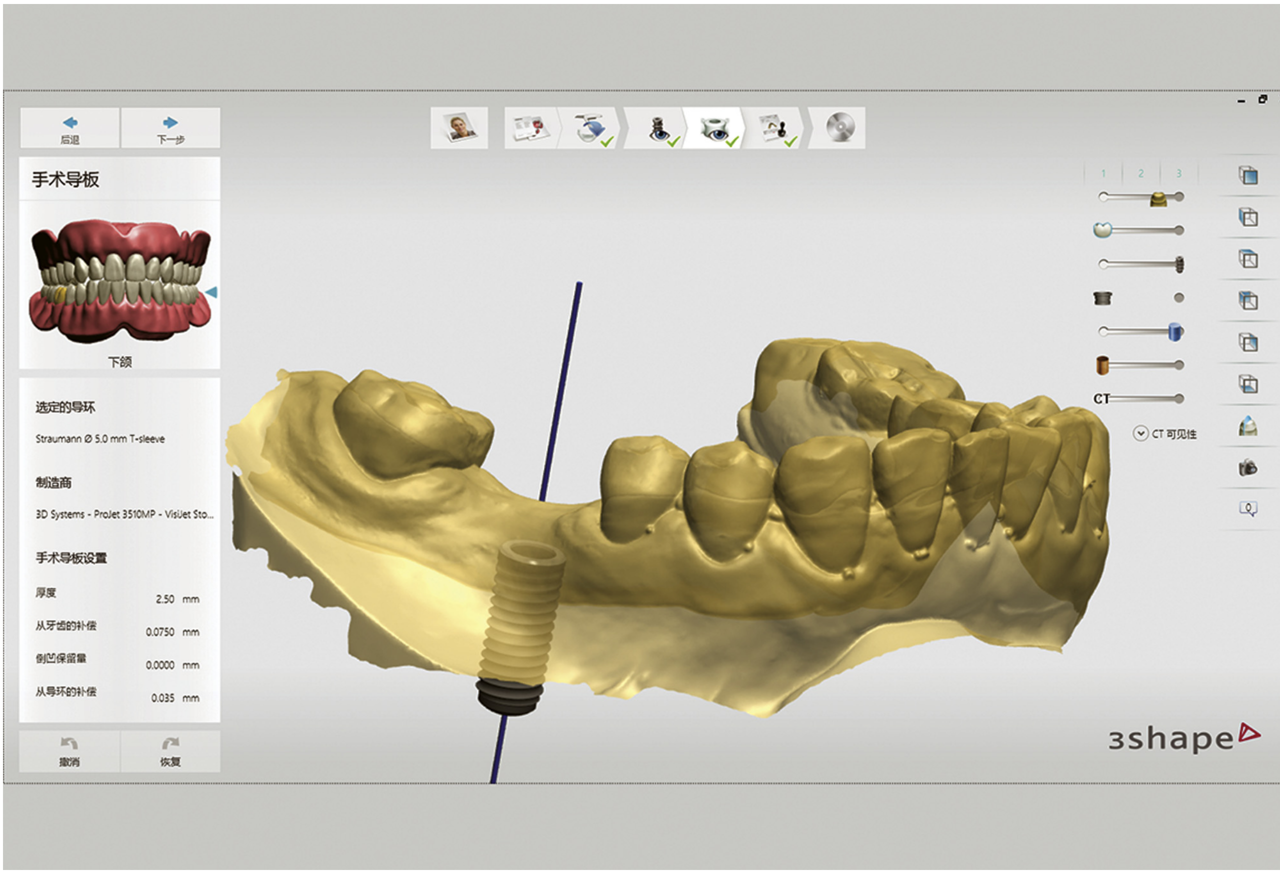

Figure 1. Surgical planning for implant surgery. Cone beam computed tomogram hidden to show implant position.

TECHNIQUE

A clinical patient with a missing mandibular right first molar was used to develop and verify the feasibility of this protocol.

1. Prepare a surgical guide by using a specialized software program (Implant Studio; 3Shape A/S) (Fig. 1). Insert the implant with the assistance of the printed guide. Export the digital cast with surgical planning in both DCM (a software-dedicated file format) and standard tessellation language (STL) file formats.
2. After osseointegration is complete, make a digital definitive cast for restoration fabrication by using an intraoral scanner (TRIOS 3; 3Shape A/S). Align the scan body image with the implant library in a dental software program (Dental System; 3Shape A/S) to determine the implant position (Fig. 2). Export the digital definitive cast with implant position as both DCM and STL files.
3. Open the digital cast DCM file in a common text editor (Notepad; Microsoft Corp) because the extensible markup language—a widely accepted, open standard for data exchange—is used in the DCM file. Find the coordinate information of each implant, which is presented as a series of properties "m00," "m01," …, and "m33," Compose the implant coordinate transformation matrix as follows:

$$M_I = \begin{bmatrix} m_{00} & m_{01} & m_{02} & m_{03} \\ m_{10} & m_{11} & m_{12} & m_{13} \\ m_{20} & m_{21} & m_{22} & m_{23} \\ m_{30} & m_{31} & m_{32} & m_{33} \end{bmatrix}.$$

4. Calculate the implant coordinates as per the software specifications (Dental System), which specify that the center point of the implant platform is to be located at the coordinate origin $P_O(0,0,0)$ and the apex is to be directed along the y-axis $V_0(0,\ -1,0)$. Multiply the transformation matrix and the specified implant origin coordinates by using a mathematical calculator to resolve the implant coordinates:

Figure 2. Digital definitive cast for prosthesis fabrication.

$$P(x_P, y_P, z_P) = \begin{bmatrix} x_P \\ y_P \\ z_P \\ 1 \end{bmatrix} = M_I \times P_O = \begin{bmatrix} m_{00} & m_{01} & m_{02} & m_{03} \\ m_{10} & m_{11} & m_{12} & m_{13} \\ m_{20} & m_{21} & m_{22} & m_{23} \\ m_{30} & m_{31} & m_{32} & m_{33} \end{bmatrix} \times \begin{bmatrix} 0 \\ 0 \\ 0 \\ 1 \end{bmatrix},$$

$$V(x_V, y_V, z_V) = \begin{bmatrix} x_V \\ y_V \\ z_V \\ 0 \end{bmatrix} = M_I \times V_O = \begin{bmatrix} m_{00} & m_{01} & m_{02} & m_{03} \\ m_{10} & m_{11} & m_{12} & m_{13} \\ m_{20} & m_{21} & m_{22} & m_{23} \\ m_{30} & m_{31} & m_{32} & m_{33} \end{bmatrix} \times \begin{bmatrix} 0 \\ -1 \\ 0 \\ 0 \end{bmatrix},$$

where $P(x_P, y_P, z_P)$ is the platform center of the implant and $V(x_V, y_V, z_V)$ is the direction of the implant.

5. Import the STL files of both the planning and definitive digital casts to a 3D reverse engineering software program (Geomagic Studio; 3D Systems). Use P and V as calculated previously and the exact implant length to create cylinders representing the implants. Attach the cylinders to the respective casts (Fig. 3).
6. Superimpose the planning cast and digital definitive cast by selecting the remaining dentition and using the "best-fit" algorithm of Geomagic Studio (Fig. 4). Record the start and end point coordinates and the direction vectors of the cylinders, which represent the platform center, apex, and direction of the implants in the same coordinate system.
7. Calculate the coronal and apical deviations of the implants by resolving the Euclidean distances of the start and points of the cylinders. Calculate the angle deviations by resolving the angles between the direction vectors of the cylinders (Fig. 5).

DISCUSSION

The presented protocol overcomes the shortcomings of the widely used analyses based on either CBCT or software-specific definitive casts. It requires no additional scan. Steps 1 and 2 are common routines in digital dentistry, and only unencrypted data from the dental software program are processed. The use of digital casts eliminates administering additional radiation to the patient. The protocol uses a similar algorithm to the built-in functions of some surgical planning software programs. However, these built-in functions are often closed loop or absent from some dental software programs. Only steps 3 and 4 are software specific. The algorithm framework of this protocol can be applied to any surgical planning or dental CAD software program if the

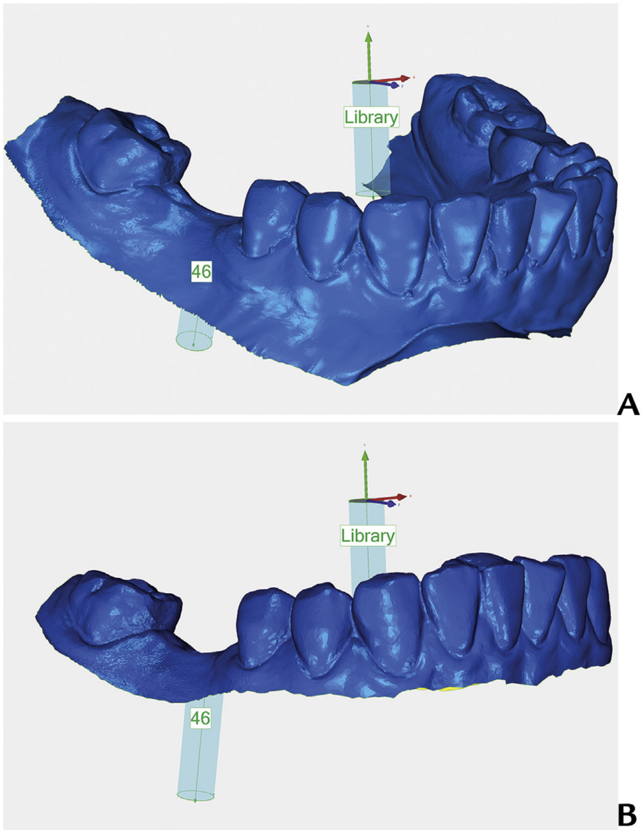

Figure 3. Reconstructed cylinders representing implants in Geomagic Studio. A, Surgical planning cast. B, Definitive cast.

manufacturer provides a way to access the implant coordinates. Steps 3, 4, 5, and 7 can be performed by pure mathematical operations by using the transformation matrix generated automatically in step 6, indicating the simplification and programmability of this protocol. Dental software program developers should provide an open interface rather than a closed-loop workflow to evaluate the accuracy for moving from research to clinical application and help dentists improve their ability to assess implants.

SUMMARY

This technique calculates implant deviation by using clinically routine digital casts without requiring CBCT scans. The protocol can be integrated into various dental software programs to overcome the shortcomings of specific closed-loop workflows.

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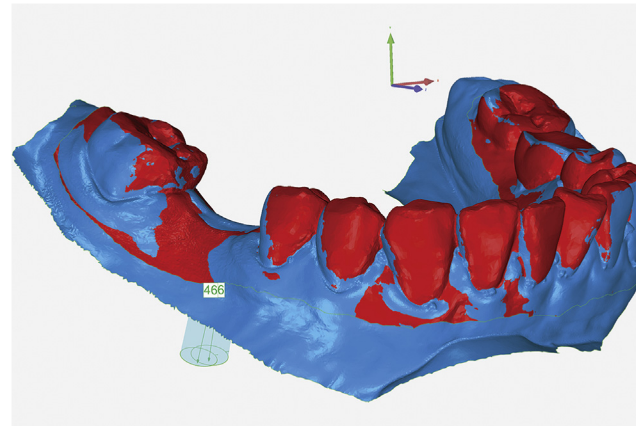

Figure 4. Superimposed digital casts with attached cylinders.

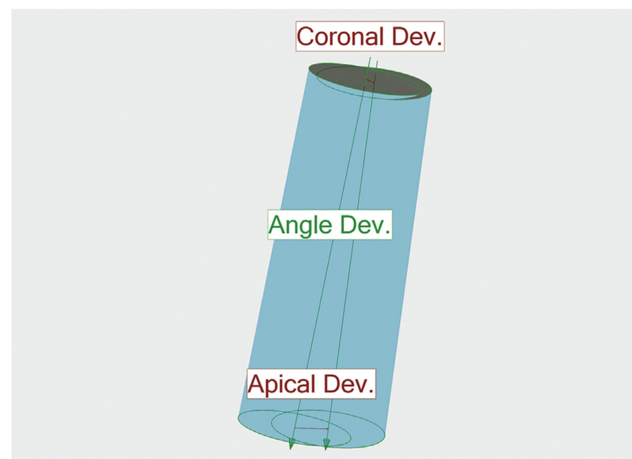

Figure 5. Implant deviation calculated based on reconstructed implant cylinders.

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