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Research article

A registration-and-fixation approach with handpiece adjustment for dynamic navigation in dental implant surgery

Bin-Zhang Wu *, Feng Sun

First Clinical Division, Peking University School and Hospital of Stomatology & National Center of Stomatology & National Clinical Research Center for Oral Diseases & National Engineering Research Center of Oral Biomaterials and Digital Medical Devices, Beijing, PR China

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ABSTRACT

The deviations between the preoperative (planned) and postoperative (actual) positions of dental implants have always been of a major concern in dental implant surgery. Dynamic computer-aided implant surgery (dCAIS) systems have been used to achieve optimal implant positioning. The method of registration is indeed an important factor that affects the implanting accuracy. Here, we propose a fast and concise registration method using a registration-and-fixation device as well as an adjustable handpiece for dynamic navigation in dental implant surgery. To the best of our knowledge, our work is the first study of such a registration method for dynamic navigation in a dental implant system.

1. Introduction

Dynamic computer-aided implant surgery (dCAIS) systems have been used in dental implant surgery for about 20 years [1, 2], in order to achieve optimal implant positioning. With the rapid developments in navigation technologies, numerous relevant research papers have been published in the past 3–5 years [3, 4, 5, 6]. In fact, dynamic navigation has several advantages:

(1) precise dental implantation in narrow spaces, accurate and safe localization of the bone mass entry point (such as in the cases of stenosis and multiple missing teeth), avoiding the maxillary sinus and the inferior alveolar nerve [7, 8], and dynamic space and angle management;
(2) aesthetic implant restorationfor anterior teeth, implementation of a restoration-oriented design, efficient use of the bone mass, and bone graft reduction;
(3) immediate loading, and multipoint precise implantation to ensure uniform force distribution and better bite force.

The principles of dCAIS might be generally stated as follows. Through optics-based spatial positioning and tracking, the positional relationships between surgical instruments and patients' dental structures are intraoperatively determined and displayed along with preoperative cone-beam computed tomography (CBCT) outcomes through spatial registration techniques. This enables accurate real-time intraoperative guidance, and allows real-time visualization and tracking of surgical instruments.

The deviations of the preoperative (planned) and postoperative (actual) positions of dental implants has always been a critically important problem [5, 9, 10]. Indeed, the implanting accuracy is highly affected by the method of registration. A fast, simple and accurate registration method shall increase the popularity and acceptance of the navigation-based implant surgery among patients and doctors. According to our clinical experience and literature, the intraoperative registration time of the available dynamic navigation implant systems is generally between 2 and 5 min for a partially edentulous jaw [11, 12]. Here, we propose a fast and accurate registration method using a registration-and-fixation device and an adjustable handpiece for dynamic navigation in dental implant surgery. To the best of our knowledge, such a registration method for a dental navigation system has not been reported earlier in the open literature.

2. Technique

This technique was approved by the Institutional Review Board of Peking University Hospital of Stomatology. I confirm that informed consent was obtained from four patients for their images to be published. The steps of the proposed registration procedure can be briefly listed as follows:

* Corresponding author.
E-mail address: wubinzhang@bjmu.edu.cn (B.-Z. Wu).

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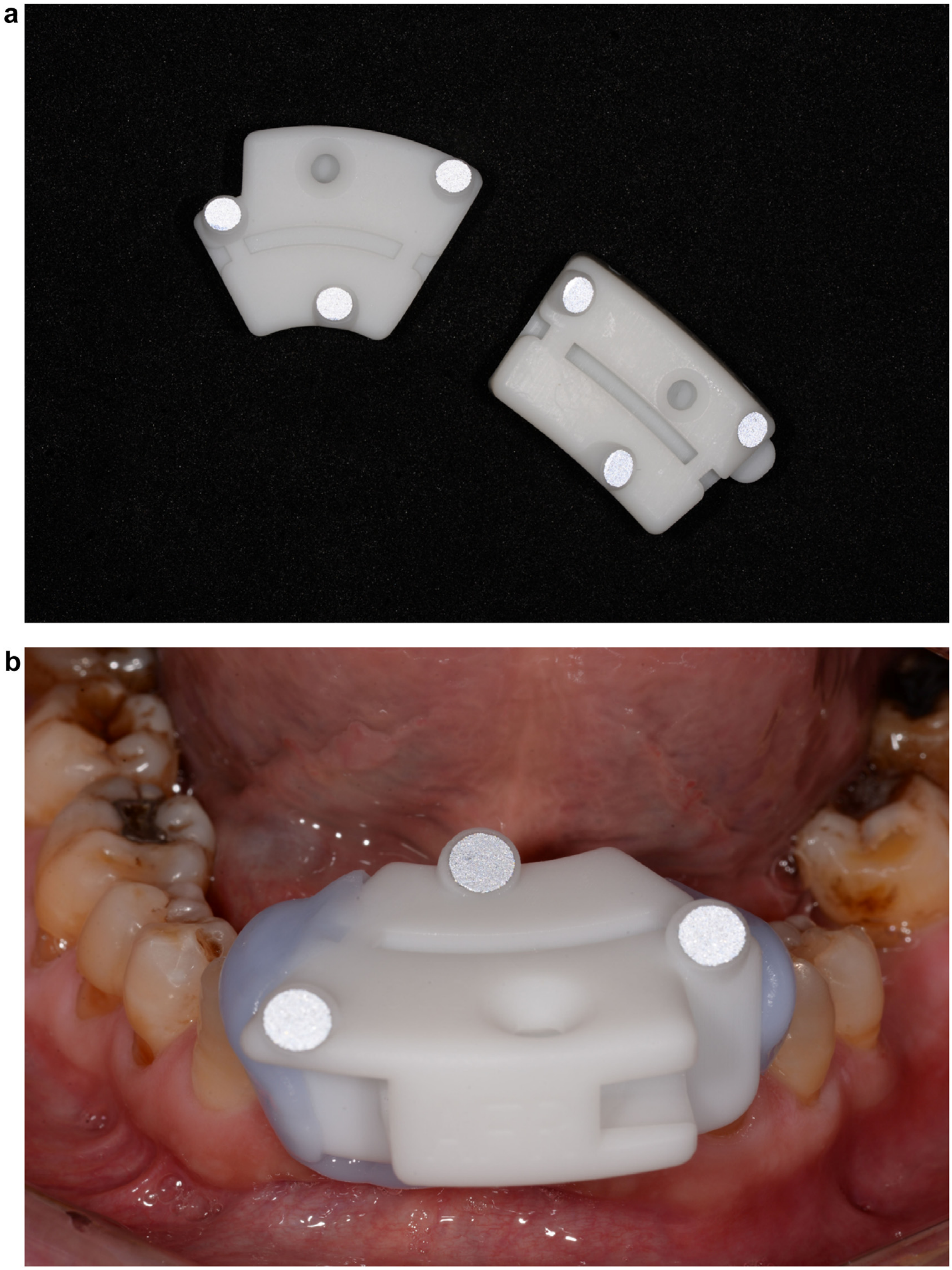

Figure 1. a. Registration-and-fixation devices for anterior and posterior teeth, respectively. b. A registration-and-fixation device put on the mandibular anterior teeth.

1. Before a dental patient undergoes CBCT scanning, we make sure to use fixed settings (90 kV, 8 mA, 8 s, voxel size: 180 μm; Crestream 9300, Crestream Health, France) for all patients. A registration-and-fixation device (with three reflective patches as radiographic markers) is mounted using a thermoplastic resin material on the solid teeth in the non-operative area of the CBCT-scanned jaw (Figures 1a and b). The reflective patches need to be clearly visible in the CBCT output and should not overlap with the teeth. So, a patient's mouth need to be open during the CBCT procedure. If the device is reset to a certain fixed position during operation, the coordinate relationship can be invariably obtained by registering the actual marker positions with the corresponding CBCT-based marker positions. After registration, the mapping of the actual jaw structure to the CBCT output is obtained.
2. The adjustable handpiece (Figure 2a) is calibrated with five gears using a handpiece-locating device and a reference device before the dental implant surgery. Each of these devices has infrared light transmitters, which actively send infrared light to the navigator for device spatial localization. Long and short ball drills are consecutively installed on the handpiece, whose orientation is determined based on an axis defined by the endpoints of the needles of the two drills. The spherical portion of each drilling needle is positioned close to the

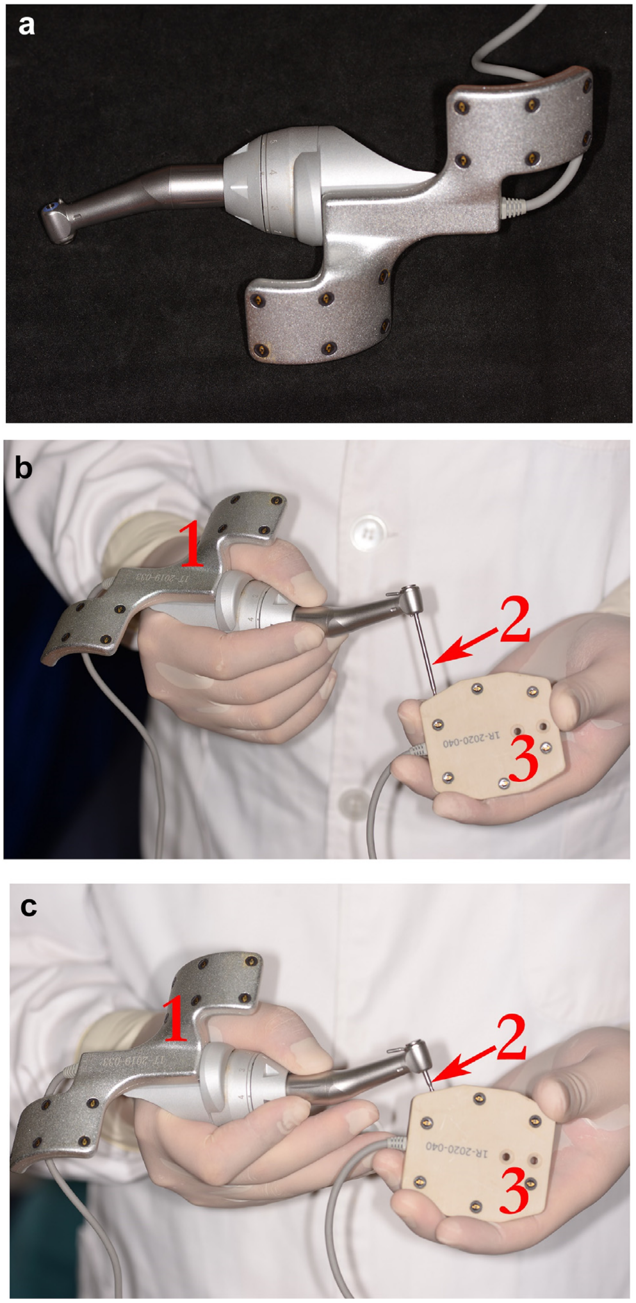

Figure 2. a. An adjustable handpiece with five gears. b. Calibrating the adjustable handpiece with a long drill using a handpiece-locating device and a reference device before the dental implant surgery. 1 - handpiece-locating device; 2 - long drill; 3 - reference device. c. An adjustable handpiece with a short drill. 1 - handpiece-locating device; 2 - short drill; 3 - reference device.

hemispherical groove on the reference device (Figures 2b and c). For this setup, the navigator collects the infrared light signals sent by the handpiece locator and the reference device in order to determine the spatial relationship between these two devices. The five gears are employed to effectively receive information from the navigator. Then, the calibrated adjustable handpiece can be directly used with the same matched reference device in the next operation. No handpiece recalibration is needed after shifting during the operation.

3. The digital CBCT data is imported into the dynamic navigation software for dental implant surgeries. For each implant, the optimal platform diameter, apical diameter, and length are chosen from the implant software library. The values of the optimal platform diameter, apical diameter, and length are 6.5 mm, 4.8 mm and 12 mm for this patient, respectively. A suitable three-dimensional virtual implant position is also planned (Figure 3). Based on the prosthetics and biology oriented design principle, the position of the prosthesis is designed first, and then the axial direction of the implant is designed according to the central position of the prosthesis. The apex of the implant maintains a certain safe distance from the inferior alveolar canal.
4. For real-time tracking of the registration-and-fixation device during navigation, this device is coupled with the reference device through a rigid rod. This rod ensures a rigid motion of the registration-and-fixation device with a fixed relative position. After obtaining the navigator coordinates, the jaw coordinates can be calculated based on the position of the reference device. The active and passive infrared registration process can be easily and quickly carried out using three reflective patches in the registration-and-fixation device and the reference device outside the mouth. This process usually takes only 10–20 s. The intraoperative procedures include connecting the reference device with the registration-and-fixation device, while ensuring that the reflective patches on the registration-and-fixation device and the infrared light transmitter on the reference device are all aligned with the navigator during the registration process (Figures 4a and b). In particular, the transmitter on the reference device actively emits infrared light signals, while the navigator receives the signals and uses them for self-localization. The navigator then emits infrared light signals which are reflected back by the reflective patches mounted on the registration-and-fixation device (Figure 4c). Upon completing this process, both the registration-and-fixation device and the reference device are accurately reset on the patient's dentition, while the positional stability of the registration-and-fixation device is ensured. Through these steps, the spatial relationships between the handpiece locator, the reference device, the CBCT output and the jaw coordinates are determined. Furthermore, the drill is placed on the cusps and tooth surface to verify the accuracy of the drill position displayed in the dynamic navigation system (Figure 4d).
5. After verifying the position accuracy, the adjustable handpiece and drills are used to perform the dental implant surgery under the dynamic navigation system. During surgery, the navigator only needs to automatically capture the unobstructed infrared light signals actively sent by the transmitters mounted on the reference device and the handpiece locator. A dental implant (SP, φ 4.8 mm, 12 mm, Straumann, Switzerland) is inserted in the left mandibular first molar area after sequentially performing four drills (φ 2.2 mm, φ 2.8 mm, φ 3.5 mm and φ 4.2 mm) (Figures 5a, b and c).
6. Each patient undergoes a CBCT scanning immediately after surgery (Figure 6). The preoperative (planned) and postoperative (actual) positions of the implants are matched using the Dcarer® software for verifying the accuracy of dynamic navigation (Figures 7a, b, c, d and 8). The differences between the planned and actual implant positions are given in Table 1 for this case and other cases using the same technique.

3. Discussion

The active infrared registration method of the dynamic navigation system was introduced by Yao et al. [8] and Wu et al. [13]. The steps of the registration procedure can be briefly described as follows. A registration device should be setup for each patient using a silicone elastomer material in the surgical site before undergoing CBCT scanning. First of all, handpiece calibration is performed intraoperatively (and not preoperatively) using the same method. Secondly, registration is performed where both the reference device and the fixation device are placed on different sides of the same jaw such that the spatial position of the reference device coincides with the position of the patient's jaw. The actual registration device is reset in the patient's mouth, while the virtual

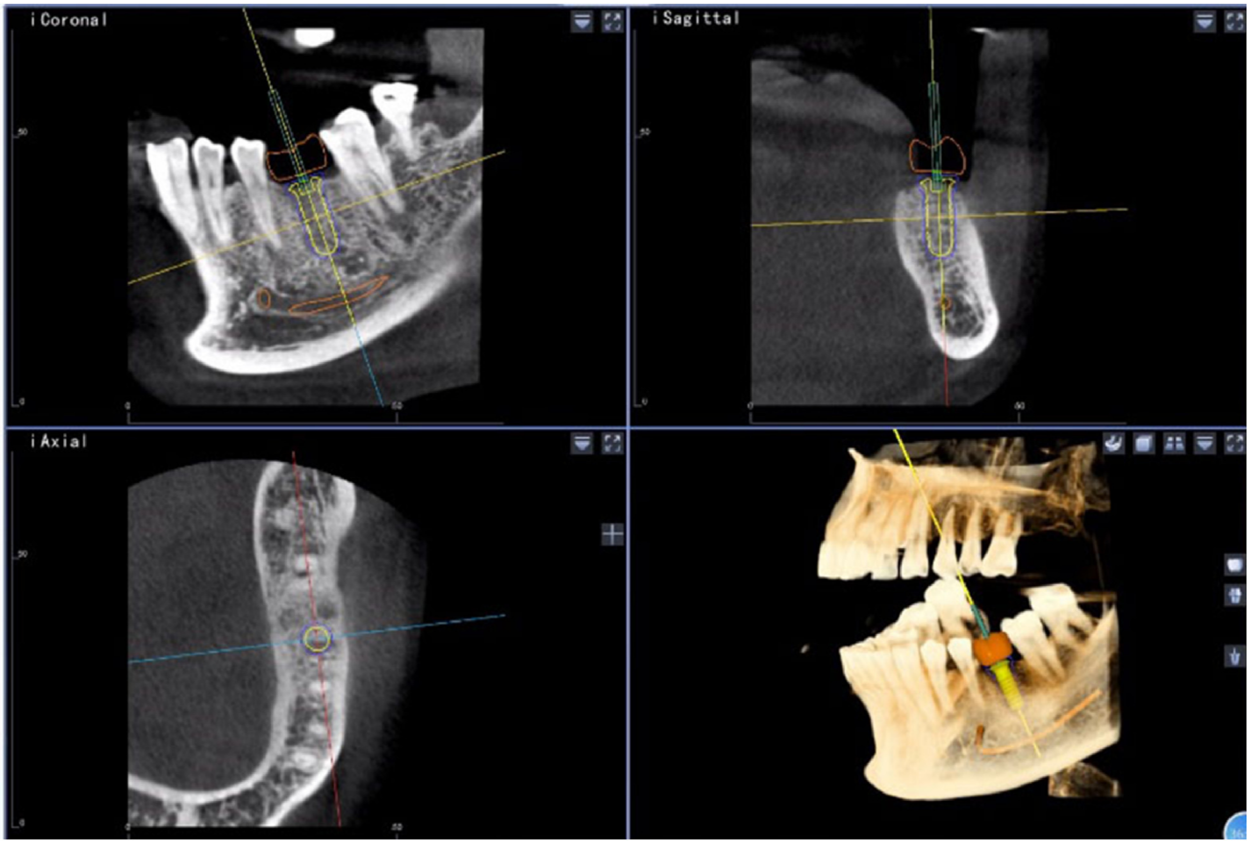

Figure 3. Suitable three-dimensional virtual position for the left mandibular first molar implant as planned in the dynamic navigation software.

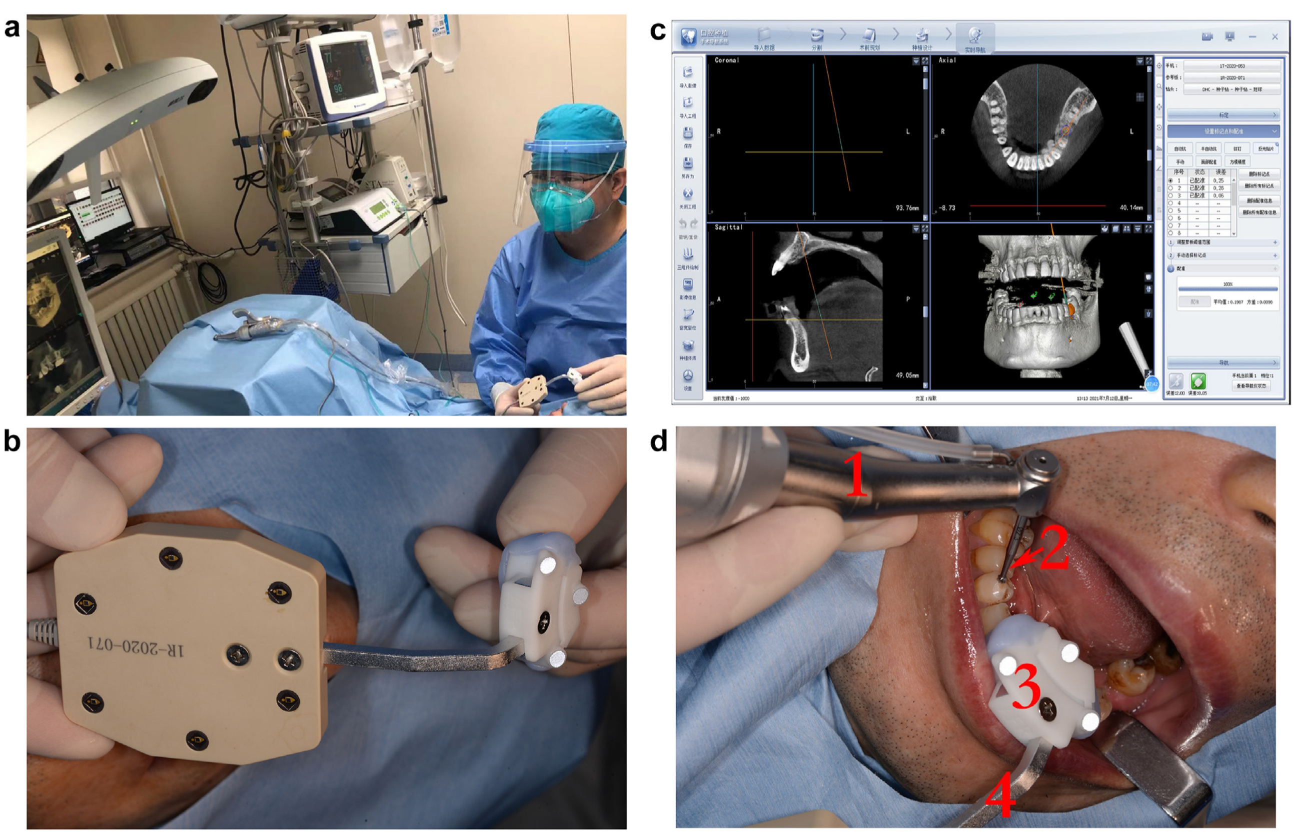

Figure 4. a. Registration using three reflective patches in a registration-and-fixation device and the reference device outside the mouth. b. Connecting the reference device with the registration-and-fixation device using a rigid rod. c. The registration accuracy displayed in the navigation software. d. Putting the registration-and-fixation device on the teeth with the reference device, and placing the drill on the tooth cusp for verifying the drill position accuracy in the dynamic navigation system. 1 - handpiece with locating device; 2 - φ 2.3 mm drill; 3 - registration-and-fixation device; 4 - rigid rod.

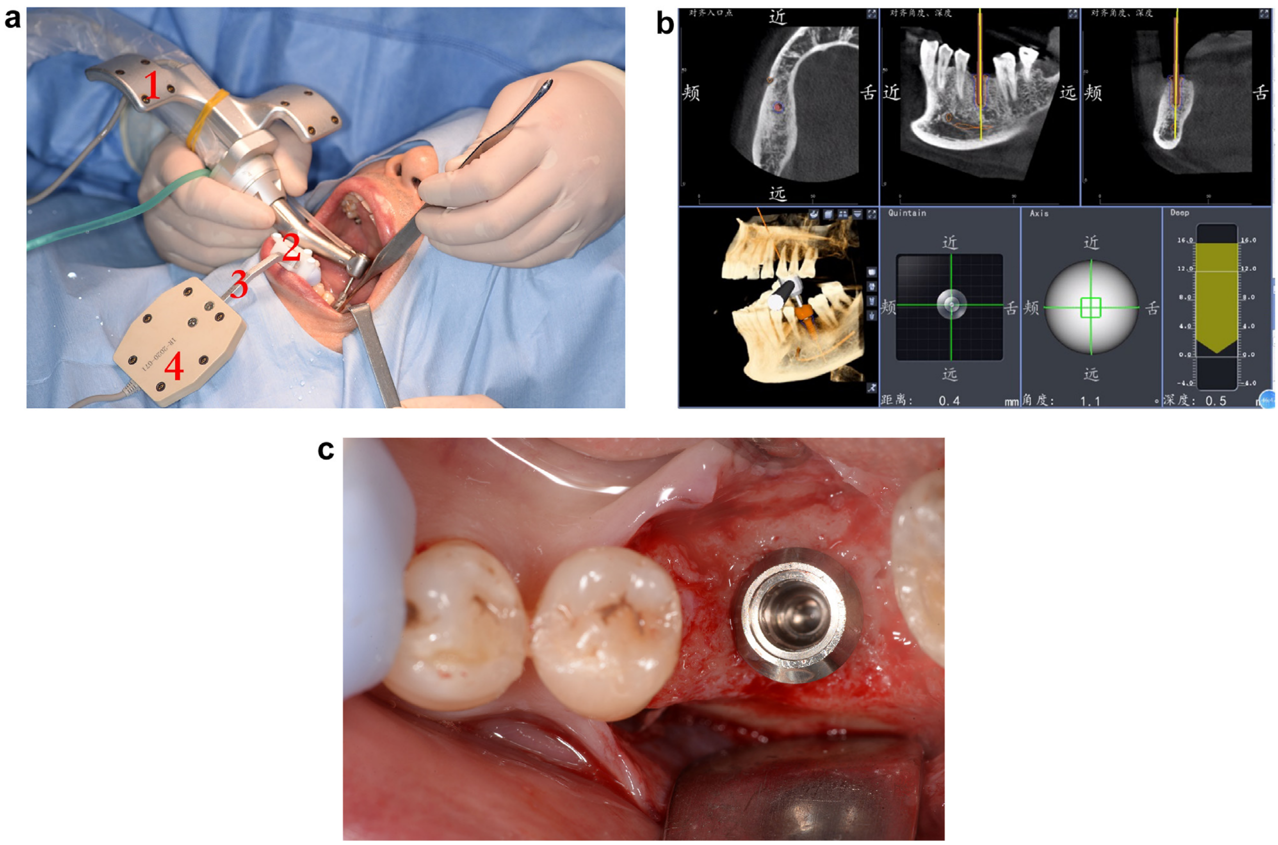

Figure 5. a. Using the adjustable handpiece and drills in the surgery of the left mandibular first molar implant under the dynamic navigation system. 1 - handpiece with locating device; 2 - registration-and-fixation device; 3 - rigid rod; 4 - reference device. b. Displaying the real-time drill direction and position on the navigation screen. c. An oral image of the left mandibular first molar implant after surgery.

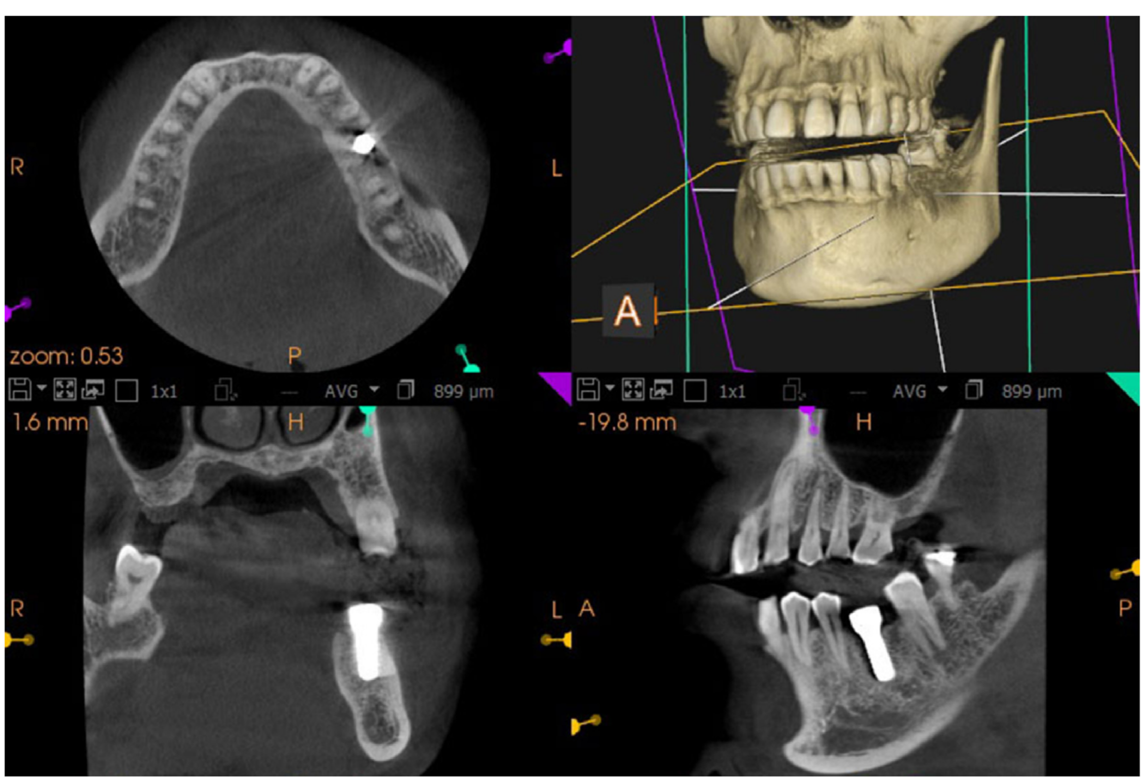

Figure 6. Postoperative CBCT scan of the left mandibular first molar implant.

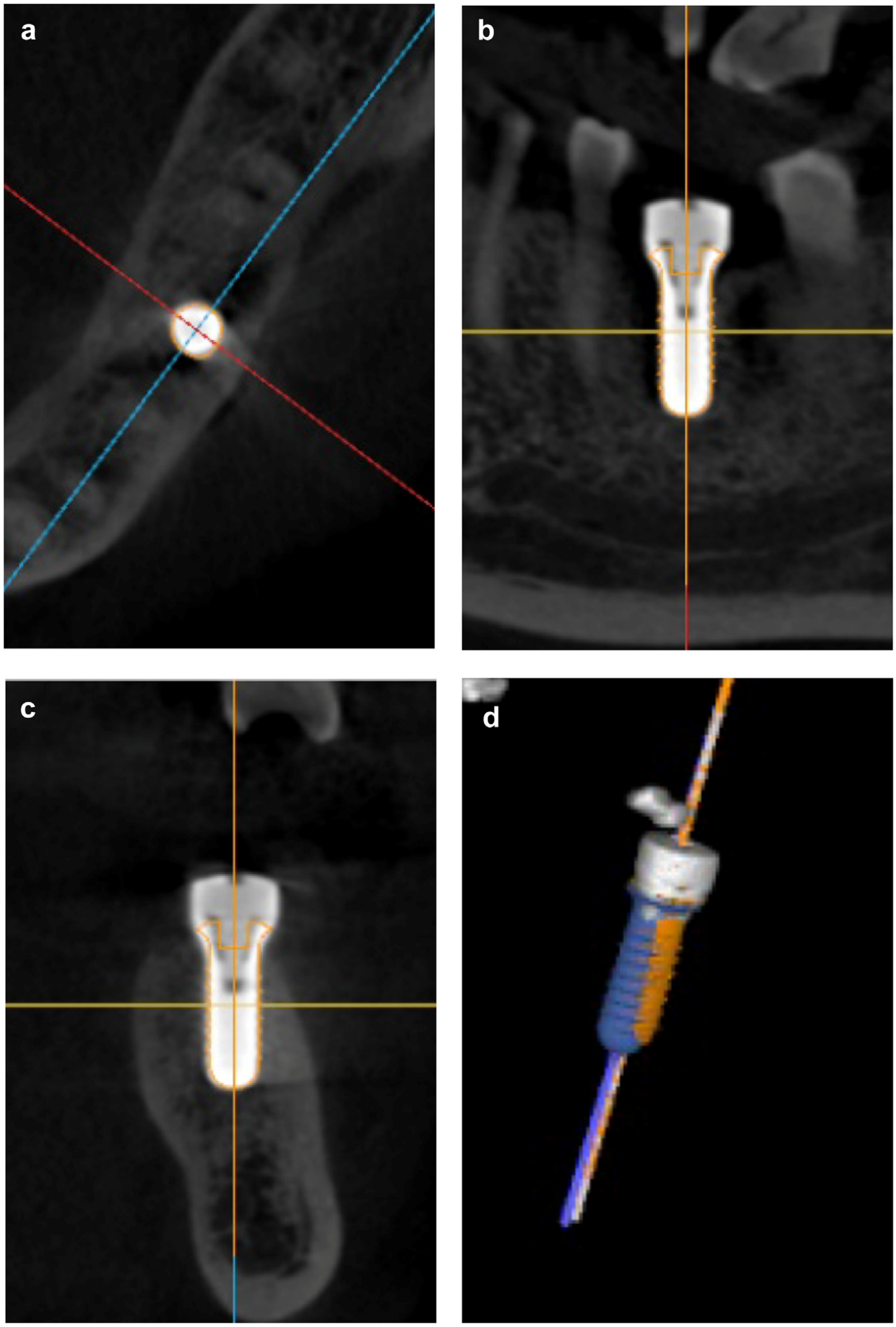

Figure 7. Accuracy evaluation in accuracy verification software, a. Implant Coronal. b. Implant Sagittal. c. Implant Axial. d. Implant three-dimensional.

registration device is reset in the CBCT output. A short ball drill is mounted on the handpiece to collect specific ball pit information (at least six marker points) on the registration device, and hence infer the spatial relationships between the handpiece locator, the reference device, the CBCT output, and the jaw coordinates. Thirdly, the registration device is removed and the drill is placed on the cusps to check the accuracy of the drill position displayed in the dynamic navigation system [8, 13].

For the proposed active and passive infrared registration method, the registration-and-fixation device is smaller than the stand-alone registration device. This method could reduce the surgery time and the intraoperative registration steps. Extraoral registration is highly acceptable among patients, and it enjoys several advantages. For example, this registration process is easy to learn with a steep learning curve. This process can also reduce the use of consumables and minimize the intra-operative navigator adjustment time. Moreover, this process does not necessitate handpiece calibration after shifting. Most importantly, this registration method leads to fewer residual teeth in any patient using the navigation-based implants. In an earlier registration method, a registration device is employed using a silicone elastomer material in the surgical site. This method cannot be used in this situation, and the edentulous jaw

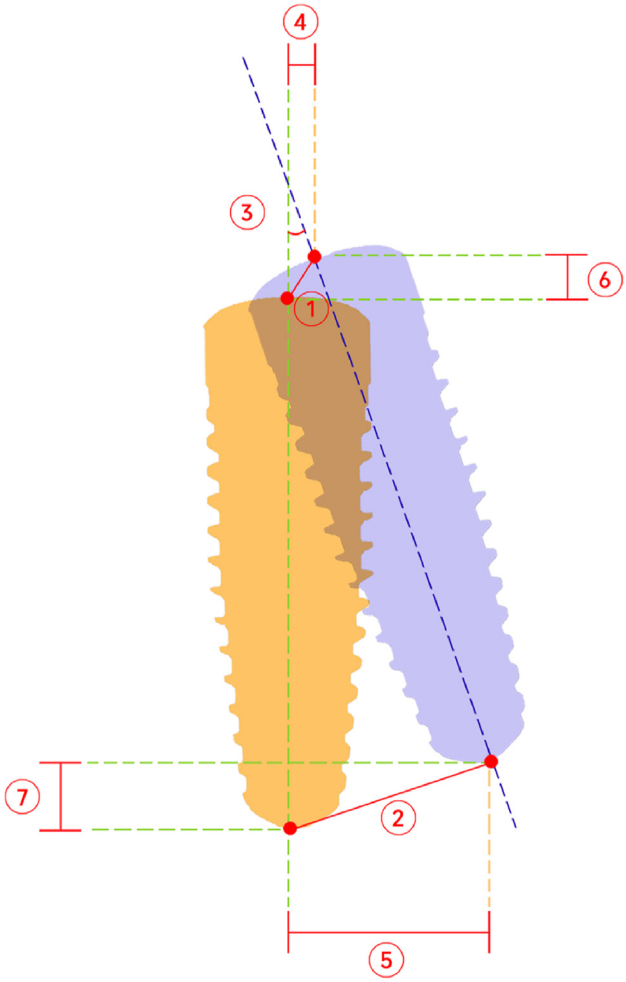

Figure 8. Deviations between the preoperative (planned, orange implant) and postoperative (actual, blue implant) implant positions. ① Entry-point deviation; ② Apical-point deviation; ③ Angular deviation; ④ Entry-point horizontal deviation; ⑤Apical-point horizontal deviation; ⑥ Entry-point depth deviation; ⑦ Apical-point depth deviation.

registration method should be adopted with titanium screws. Based on this work, a registration-and-fixation device usually needs only 4 anterior teeth or 3 posterior teeth in order to complete the reported registration process. This advantage reduces the patient's trauma and optimizes the overall process. The registration-and-fixation device may have advantages in partially edentulous patients with distal extensions. However, this registration method also has some limitations. Firstly, this method cannot be applied in patients with loose residual teeth. Secondly, the reflective patches associated with the registration-and-fixation device are not within the implant area, and this may reduce the implant positioning accuracy. Thirdly, this device has only three reflective patches to complete registration, which may lead to low fault tolerance rate.

This proposed technique is quite similar to that reported by Block et al. [10, 14], but there are still some key differences between this system and theirs. The system reported by Block et al. [10, 14] utilizes visible light, while this system employs infrared radiation. Moreover, their system involves passive registration, while this system deals with both active and passive registration. Finally, the position tracker of the system reported by Block et al. [10, 14] is relatively heavier than this system.

The teeth marks should be clearly identified and the learning curve might be less steep using cusp matching in comparison with the dynamic navigation system reported by Stefanelli [12]. The proposed technique cannot also be used for mobile teeth. The whole registration process usually takes 1–2 min. If the registration accuracy is not acceptable, further registration refinement should be made [12].

The proposed method could achieve fast registration. We measured seven effective deviations between planned and actual implant positions, including entry-point deviation, apical-point deviation, angular deviation, entry-point horizontal deviation, apical-point horizontal deviation, entry-point depth deviation, and apical-point depth deviation. These average values were 0.862 mm, 0.914 mm, 1.629°, 0.287 mm, 0.445 mm, 0.768 mm and 0.765 mm, respectively. In a recent systematic review of the accuracy of dynamic computer-aided implant placement, Jorba-García et al. reported an average angular deviation of 3.68°, an average coronal global deviation of 1.03 mm, an average apical global deviation of 1.34 mm, an average lateral (2D) entry of 0.69 mm, an average lateral (2D) apex of 0.9 mm, an average apex depth of 0.73 mm and an average entry depth of 0.50 mm in clinical studies [3]. The postoperative results obtained herein were relatively accurate. However, more patient cases are needed to confirm the accuracy of this dynamic navigation system in dental implant surgery. In future work, randomized controlled trials shall be carried out to verify the clinical feasibility of the proposed infrared registration method. Also, surgeons with different experience levels and more patients should be involved, and feedback should be collected on the quality of experience with the proposed system. This feedback could help identify the types of teeth loss and the dentists' experience levels that are the most suitable for the proposed method. This can lead to rapid registration, and highly accurate and safe results.

4. Summary

The method of registration is an important factor affecting the accuracy of an oral implant procedure. We describe a fast and accurate registration method based on a registration-and-fixation device and an adjustable handpiece for dynamic navigation in dental implant surgery. More cases are needed to confirm the clinical feasibility of the proposed method.

Table 1. Outcomes of accuracy measurement between planned and actual implant position.

Case (Position)	Implant Data	EPD (mm)	APD (mm)	AD (°)	EPHD (mm)	APHD (mm)	EPDD (mm)	APDD (mm)
Case 1 (36)	Φ 4.8 × 12 mm (Straumann)	0.686	0.800	1.156	0.269	0.495	0.631	0.628
Case 2 (37)	Φ 4.8 × 10 mm (Straumann)	1.077	1.133	2.523	0.228	0.452	1.052	1.040
Case 3 (36)	Φ 4.1 × 10 mm (Straumann)	1.089	1.125	0.863	0.137	0.322	1.080	1.079
Case 4 (14)	Φ 4.3 × 11.5 mm (Nobel)	0.597	0.599	1.974	0.513	0.511	0.307	0.313
Mean		0.862	0.914	1.629	0.287	0.445	0.768	0.765

EPD: Entry-point deviation; APD: Apical-point deviation; AD: Angular deviation; EPHD: Entry-point horizontal deviation; APHD: Apical-point horizontal deviation; EPDD: Entry-point depth deviation; APDD: Apical-point depth deviation.

Declarations

Author contribution statement

Bin-Zhang Wu: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Feng Sun: Conceived and designed the experiments; Wrote the paper.

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Data availability statement

Data will be made available on request.

Declaration of interest's statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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