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Original Article

The influence of cone beam computed tomography on IRIS-100 implant navigation system

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KEYWORDS
Dental implant navigation system;
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Abstract *Background/purpose:* Cone beam computed tomography (CBCT) is frequently used in dental diagnosis and treatment. Comparative studies of the effects of CBCT on implant navigation, however, are still limited. The objective of this study was to evaluate whether the computed tomography images of the four commercial brands will affect the accuracy of the new version of IRIS implant navigation system.
Materials and methods: In the first part, the accuracy of the IRIS implant navigation system was evaluated by a precision confirmation jig whose position is confirmed. In the second part, the IRIS implant navigation system was used in conjunction with 4 brands of CBCT scans analyzed by its effect on accuracy.
Results: The results showed that the mean deviation of the new version of IRIS-100 system accuracy was less than 1 mm. Among the four groups, the overall average deviation caused by CBCT images showed that the 3D eXam group had the smallest error of approximately 0.94 ± 0.12 mm and the AZ 3000 CT group had the largest error of approximately 1.34 ± 0.10 mm.
Conclusion: Based on the study, the accuracy of the IRIS implant navigation system will vary with the CBCT image resolution and the status of the CBCT machine.

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Introduction

Combining real-time imaging and software computing technologies is a popular surgical navigation technique that is gaining popularity in the medical field. This technique is widely used in orthopedics, blood surgery, tumor surgery, neurosurgery, and other fields to improve the outcomes of surgery. In dentistry, this technology has already been used in reconstruction following tumor surgery, orthognathic surgery, post-trauma reconstruction, and dental implant surgery.[1]

Modern dental implant surgery aims to provide long-lasting dental function, achieve an aesthetic result, minimize complications, reduce operation time and treatment duration. Implant surgery methods can be roughly divided into 4 categories: the free hand method of directly performing the implant surgery; the limited guidance method, which uses a surgical template made using a model in the laboratory; the static method, which uses a static guiding bracket generated using computer-aided design and manufacturing (CAD/CAM); or performing surgery using a navigation system.[2]

The static system requires a laboratory guiding template or a static guiding template generated by CAD/CAM. The implantation position used in these two methods depends on the prefabricated guiding template, but the implantation position cannot be modified in response to changes during the operation.[2] The dynamic system is a system developed to allow the surgeon to see the position of the implant while drilling during dental implantation. That is, the dynamic system enables the surgeon to visualize "in real time" the deviation of the implant position from the predetermined position in their plan, and the surgeon can modify the plan at any time during the operation without abandoning the original implant surgery plan.[3] Thus, a comprehensive and complete guidance can be achieved and positional adjustments can be made responsively and in real time during the operation.[4] Therefore, the advantages of dynamic navigation system are as follows: (1)Avoid injury to important anatomical structures, (2)Minimize the need to turn the gingival flap during surgery to achieve the concept of minimally invasive surgery, (3)Accurate placement of multiple implants with proper spacing and angle, (4)Precise placement of single implants in locations with limited mouth opening or in highly esthetic areas of anterior teeth.[2]

The development of CAD/CAM systems has driven the progress of digital dentistry. CAD/CAM systems comprise image acquisition (digitizers), design software (CAD software), and production (CAM) components. Image acquisition in the dynamic navigation system use techniques such as real-time three-dimensional (3D) scans with an accurate fiducial system and calibration and registration of the fiducial markers to convert the dental form into a real-time 3D digital image. Current imaging technologies include touch-probe scanning, laser optical scanning, and the latest optical imaging synthesis technology (optical cameras).[5] In this study, an infrared sensor was used for the implant real-time imaging system to investigate whether differences in image quality between four different brands of CBCT images affect the validation precision when the system images are superimposed with the CBCT images during the operation of the navigation system. We aimed to conduct preoperative diagnosis and evaluation and to provide accurate, real-time, and practical surgical information by combining a spatial image tracking system, CBCT images, and navigation software.

Materials and methods

In this experiment, the implant real-time imaging system (IRIS-100 navigation system, EPED Inc., Kaohsiung, Taiwan) was used to verify whether the overall positioning precision of the system met the standard of less than 1 mm (Fig. 1). Because the angle, depth, and orientation required by the system are directly related to the spatial positioning information reported by the surgical instrument and because they directly affect the coordinate information of the pin tip, the coordinates of the pin tip of a specific probe were obtained as a quantitative index for precision verification.

System precision analysis

A precision confirmation fixture with a confirmed position was selected (12 points in total), and 4 points were subsequently selected for calibration (Fig. 2). The tip coordinates of a specific probe were output by a test program. A total of 100 pieces of tracking data were collected for each hole, and the average value was taken to obtain the output coordinates of the spatial image tracking system. After obtaining the output coordinates and comparing them with the confirmed coordinates, the following equation was used to calculate the mean and standard deviation of the coordinates; the calculated values were in turn used to validate the spatial image tracking system (not including the additional parameters).

$$\sqrt{(X_2 - X_1)^2 + (Y_2 - Y_1)^2 + (Z_2 - Z_1)^2}$$

Overall precision analysis with CBCT images

The graphic information for the fixture revealed the theoretical coordinates of the 8 holes and 4 ceramic beads in the fixture, and the ideal coordinates of the 8 holes in the CT coordinate system were obtained by the alignment of the theoretical and CT coordinates of the ceramic beads (Fig. 3). Four types of CBCTs were used, namely Picasso-Trio (Vatech, Hwaseong-si, Korea), AZ3000CT (Asahi, Kyoto, Japan), 3D eXam (KaVo, Biberach, Germeny), and VGi (NewTom, Imola, Italy). After completing the registration process, the IRIS-100 software output function outputs the coordinate value of the pin tip of a specific probe. The average value of the 100 pieces of tracking data collected for each hole was used to obtain the output coordinate value of the spatial image tracking system. The ideal coordinate values of the 8 holes were then compared with the output coordinate values to validate the spatial image tracking system. The calculation of the average value of each hole was repeated for 4 rounds, and thus 32 pieces of data were obtained to verify the reproducibility of the system and. A total of 32 cases of implant position simulation analysis were completed.

Figure 1 The equipment of IRIS-100 contained with an infrared optical sensor.

Results

System precision analysis

The average coordinate error of each point in the 12 holes was 0.49 mm, and the maximum and minimum differences were 0.71 and 0.25 mm, respectively; thus, the precision error met the requirement of less than 1 mm. However, this precision calculation did not include the error contributed by the CBCT images because of the inconsistent imaging quality of captured CBCT images. To evaluate validity, we first analyzed the error caused by the system itself and concluded that if a perfect CBCT image was used,the IRIS-100 navigation system software can achieve this accuracy. The effects of CBCT images are investigated in the next section.

Overall precision analysis with CBCT images

The offset for the 4 types of CBCT (Picasso-Trio, AZ3000CT, 3D eXam, and VGi) in the *x*-, *y*-, and *z*-axis are presented in Fig. 4. The analysis revealed that the offset for all 4 brands were less than 1 mm on each axis. Piccaso-Trio had negative values for the *x*- and *y*-axis coordinate offset points; the *z*-axis coordinate offset point had a positive value. AZ-3000T had negative values for the *x*- and *z*-axis coordinate offset points; the *y*-axis coordinate offset point had a positive value. 3D eXam has positive values for the *x*- and *y*-axis coordinate offset points; the *z*-axis coordinate offset point had a negative value. Finally, VGi had negative values for the *x*- and *z*-axis coordinate offset points, and the *y*-axis coordinate offset points was positive value. The maximum *x*-axis displacement measurement was AZ-3000T, the minimum was Picasso-Trio. The maximum *y*-axis displacement measurement was 3D eXam, and the minimum was VGi. The maximum *z* -axis displacement measurement was the Picasso-Trio, and the minimum was 3D eXam. No matter which kind of CBCT, the offset degree of *z*-axis was larger than that of *x*- and *y*-axis.

The discrepancy measurement revealed significant differences in differences in the *x*, *y* and *z* values among the 4 groups (One-Way ANOVA, $P < 0.05$). For *x* values, the 3D eXam group significantly differed from the other 3 groups (Tukey's HSD, $P < 0.01$). The *y* value was significantly different between the 3D eXam group and the Piccaso-Trio group (Tukey's HSD, $P < 0.01$). Finally, the Piccaso-Trio group also significantly differed from the other 3 groups for the z value (Tukey's HSD, $P < 0.0001$)

A comparison of the error distance between the pre-measurements and post-measurements of the 4 CBCT groups revealed that the AZ 3000 CT group had the largest error of approximately 1.34 ± 0.10 mm, and the 3D eXam group had the smallest error of approximately 0.94 ± 0.12 mm (Fig. 5). Further analysis revealed that the error distance of AZ 3000 CT was significantly larger than that of the 3D eXam group (Tukey's HSD, $P < 0.05$). Moreover, the correlation between the offset distance and the error distance of each axis was analyzed, and the results revealed a significant positive correlation between the *x*-axis offset distance and the error distance (Spearman's correlation 0.8841, $P < 0.0001$). The offset distance between the *y*- and *z*-axis had a significant negative correlation (Spearman's correlation -0.6622, $P < 0.001$)

Discussion

The implant navigation system enables the surgeon to use a different operation method other than the traditional operation method by integrating both clinical computed tomography images and actual data from the patient's oral cavity. However, the navigation system and the preoperative plan determined by the surgeon must be sufficiently accurate without excessive error. Therefore, the system itself should be calibrated during use such that the tracking host can accurately obtain the relative positions of the hand tool and the patient's dental arch. During the initial stage of the implant surgery, surgeons should ensure that the implant position matches the planned position shown on the screen after each use of the implant drill.

For the time being, the navigation system can be divided into two methods: electromagnetic tracking and optical tracking.

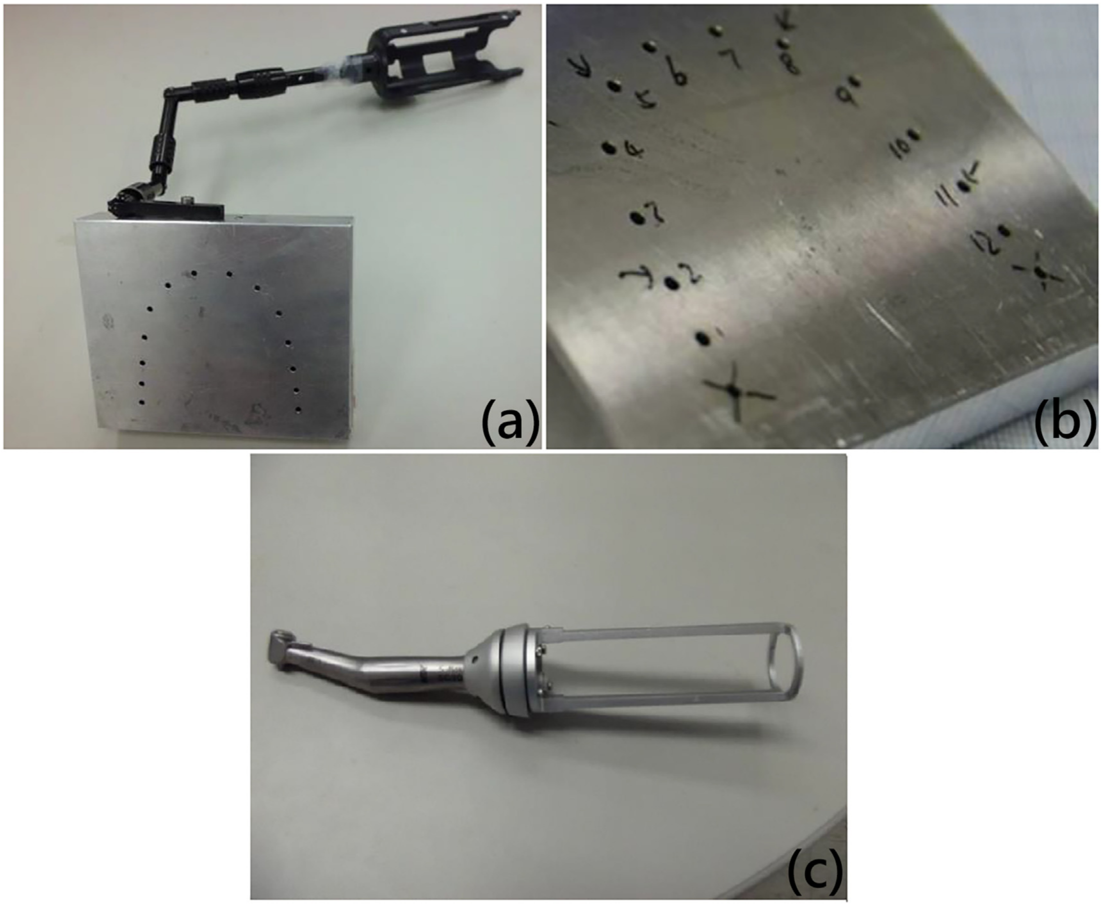

Figure 2 System precision analysis. (a) A precision confirmation fixture with a confirmed position and 12 points in total. (b) Four points were selected for calibration. (c) An implant handpiece combined with a reflective ring was demonstrated.

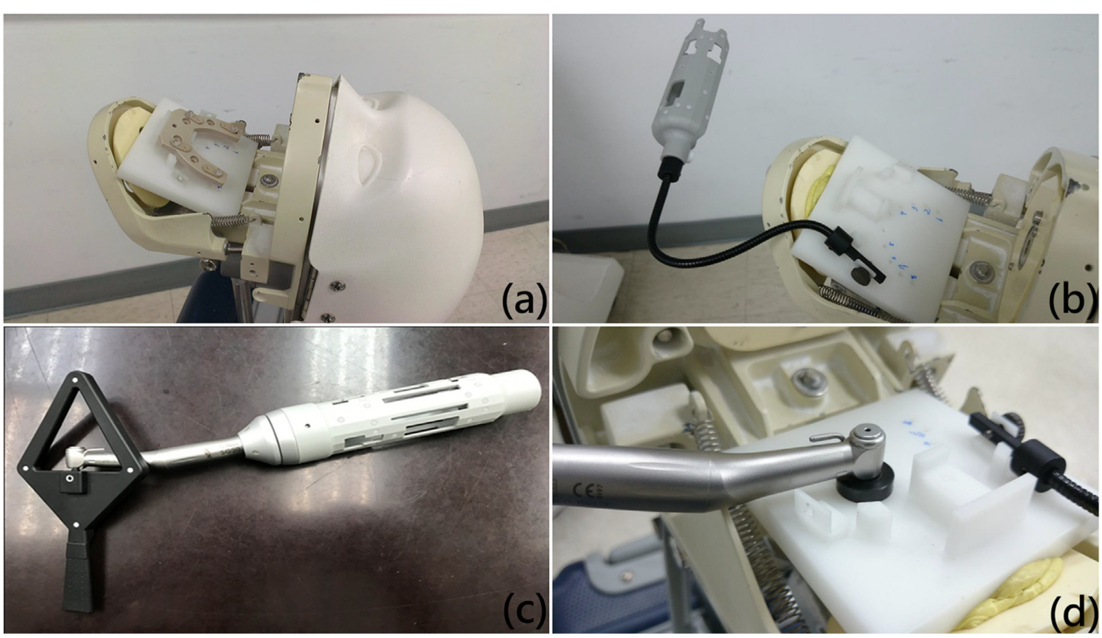

Figure 3 Overall precision analysis with CBCT images. (a) and (b) The graphic information for the fixture revealed the theoretical coordinates of the 8 holes and 4 ceramic beads in the fixture. The ideal coordinates of the 8 holes in the CT coordinate system were obtained by the alignment of the theoretical and CT coordinates of the ceramic beads. (c) The IRIS-100 software output function produced the coordinate value from the pin tip of a specific probe. (d) The tracking data were collected for each hole.

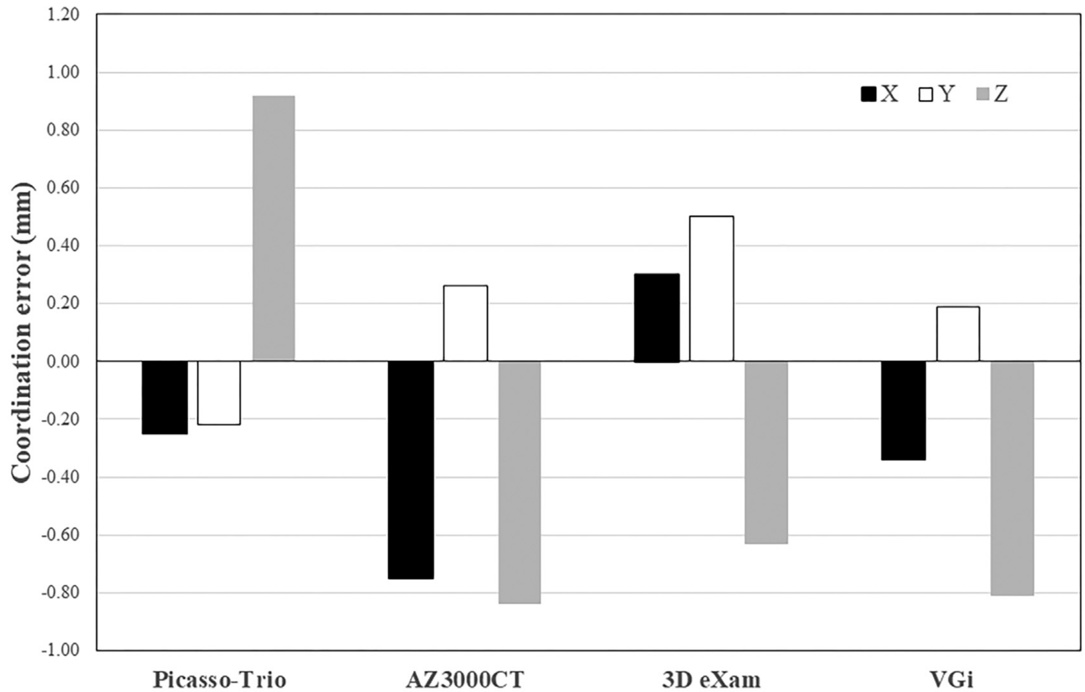

Figure 4 The offset for the 4 types of CBCT (Picasso-Trio, AZ3000CT, 3D eXam, and VGi) in the *x*-, *y*-, and *z*-axes are presented. Each column represented the mean and standard deviation.

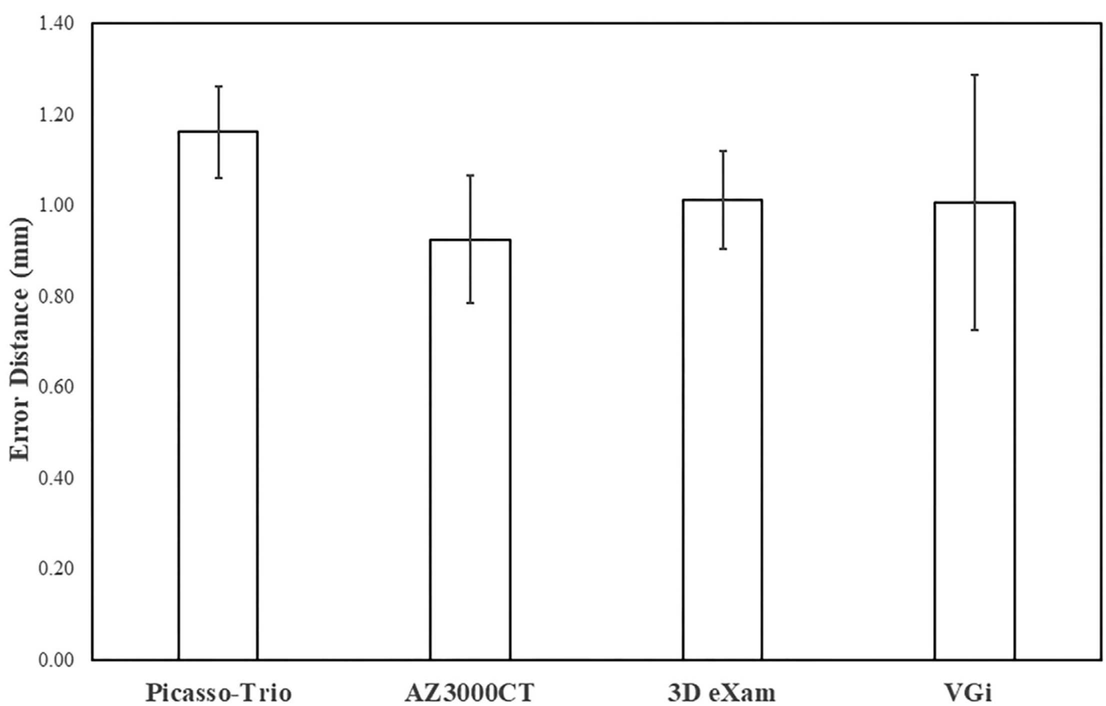

Figure 5 A comparison of the error distance in the 4 CBCT (Picasso-Trio, AZ3000CT, 3D eXam, and VGi) groups. Each column represented the mean and standard deviation.

During dental implant surgery, because the bone drill is made of metal, if the electromagnetic induction tracking method is used, it will easily interfere with the electromagnetic signal affecting its accuracy.[6] In addition, electromagnetic induction tracking needs to use non-iron containing materials to receive electromagnetic signals, and light induction can track any material objects without being affected by iron or other objects made of metal.

Another advantage of optical tracking navigation systems is that they can track the distance of objects in a large range, which is convenient for surgeons for them to move around inside the operation move and around the patient without being limited to certain areas.

According to the relationship between the tracking object and the light source, optical tracking and navigation can be divided into active tracking and passive tracking. The passive tracking system installs the light source around the camera, and the tracked object installs a reflector object to reflect the light source on the object. At this time, the camera will capture the reflected light source and then perform calculation by the program to locate the position of the tracking object. The advantage of passive optical tracking is that there is no need to install a light source on the tracking object, which reduces the weight of the instrument and is convenient for the operator to use. In addition, passive optical tracking is easier to image uniformly because the light source is fixed, and the reference of the tracked object is high.[7] Therefore, the IRIS-100 navigation system adopts infrared passive optical sensor tracking, which can perform implant of any brand.

The use of the dynamic navigation system depends on whether the system itself is sufficiently accurate, and relevant studies have determined that optical navigation systems have high precision with average error values of $\leq$1 mm. The IRIS-100 machine uses infrared detection and has an average error value of approximately 0.49 mm; the maximum value is 0.71 mm and thus meets the requirement of $<$1 mm error. Therefore, the precision of the machine itself is sufficient. A study conducted by Emery et al., in 2016 reported that four other implant dynamic navigation systems on the market, namely X-Guide, Robodent, IGI, and NaviDent, have precision between 0.21 and 1.71 mm.[8] Compared with the aforementioned navigation system, Iris-1000 has high precision; it both outperforms the other aforementioned systems and outperforms free-hand dental implantation, which typically has an error value of approximately 1.89 mm indicated in the literature.[8]

In this study, *x*-axis is defined as the bucco-lingual direction. Although the *x*-axis error values of the four CBCTs (whether positive or negative) are all less than 1.0 mm, the AZ 3000 T is close to 1 mm. If the patient's bone width in bucco-lingual direction is narrow, the 1.0 mm errors may affect the amount of bone graft placed. The *y*-axis is the MD direction, and the maximum error value of the four CBCTs is about 0.52 mm. The error of *y*-axis is smaller than that of the *x*-axis. If the edentulous with a small distance between the front and rear teeth, the diameter of the implant should be carefully selected to avoid accidental contact with adjacent teeth, or bone loss due to being too close to adjacent teeth. The *z*-axis is vertical direction and is highly correlated with the bone height. No matter which CBCT is, compared with the *x*- and *y*-axis, the *z*-axis has the largest error value. The absolute value of the error is 0.77—1.05 mm, and the AZ 3000 T is the largest. Therefore, when carrying out the posterior maxillary and posterior mandibular areas, considering the anatomical structures such as the sinus floor, the inferior alveolar canal and the metal foramen, it is necessary to keep a large safety margin.

The overall precision of CBCT images from different brands achieved in combination with the IRIS-100 dynamic navigation system ranged from 0.94 to 1.343 mm, and the error distance of AZ 3000T is significantly larger than that of 3D eXam, indicating that the image presentation of different brands of CBCT does affect the accuracy.

Casap et al. believe that the magnitude of the error varies depending on a number of factors, including the quality of the CBCT images, the precision of the tracking system, and the degree of fit of the intraoral acrylic splint.[9] Brief et al. suggested that image quality, navigation tracking system, registration procedures, and interaction factors affect the precision of CBCT image guidance.[10] Among these factors, image quality has the greatest effect because surgeons use image data in surgery planning to evaluate the patient's anatomical configuration and determine the position of the implant; the image quality also affects the registration precision. If the fiducial markers in CBCT images are not accurately positioned, the accuracy of image data registration that matches the patient's actual relative position could be reduced.

CBCT image quality reported that CBCT equipment with greater field-of-view can more easily capture accurate images. Moreover, the following points should be noted before capturing images using CBCT. First, the target object should be placed at the center of the window to maximize the accuracy of the captured image. Second, metal fillings or metal dentures in the patient's mouth can cause image scattering, affecting interpretation. Therefore, these metal objects should be removed if possible. Third, when CBCT image is taken, the occlusal height may be elevated due to the fixture and the fiducial mark that is fixed in the patient's mouth; this may in turn affect the occlusal position. When making dentures, an articulator should be used to determine the occlusal relationship between the upper and lower jaws to avoid being misled by the images. Fourth, when performing 2D image measurements using CBCT, the thickness of the image should be set larger than the size of the surgical implant for a more accurate diagnosis. Fifth, if the soft tissues of the lips and lateral tongue are not separated from the gums, determining the thickness of each soft tissue is impossible. Thus, isolation using dry gauze or a positioner is recommended.

The IRIS-100 navigation system includes a feature point planning calibration method. That is, the feature points of the teeth in the 3D stereoscopic structure of the CBCT image are used as reference points during registration. Examples of feature points include relatively obvious dental features such as the cusp and the central fossa on the molar. The feature points on these images can be registered in relation to the position of the teeth in the model or patient, increasing the precision of the system image registration and reducing the errors caused during registration.

The IRIS-100 navigation system uses an open system for drill pins and hand tools. By entering the sizes of the drill pins and hand tools, the information for each brand can be determined; thus, the system can be used regardless of which brand.

In general, the accuracy of the system will vary with the CBCT image resolution and the status of the CBCT machine. It can be confirmed that the accuracy deviation of the spatial image tracking system can be less than 1 mm, but the accuracy deviation will vary with the influence of CBCT images and CBCT machine conditions.

Conflict of interest

The authors have no conflicts of interest relevant to this article.

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