With the advent of CBCT and CAD/CAM technology, digital surgery guides have started to play an essential role in oral implantology. The accuracy of implant placement has improved significantly with the help of a digital implant guide. The concept of “restorative-driven implants” has been transformed into reality, and clinicians can place implants that are more conducive to restoration or in a safer position.\(^1,2\)

The deviation of implant placement cannot be avoided even when a surgical guide is used.\(^3,4\) According to the ITI Consensus Report in 2018, the mean 3D deviation for static computer-aided implant surgery (sCAIS) was 1.2 mm at the entry point and 1.5 mm at the apical position, and the angular deviation was 3.5 degrees.\(^5\) Several in vivo and in vitro studies have focused on the accuracy of sCAIS with fully guided systems, indicating that increasing the level of guidance increases accuracy.\(^6–11\) However, a randomized controlled trial showed that fully guided surgeries were more accurate than partial and pilot guide protocols, which still produced an angular deviation of 3.01 ± 1.51 degrees, a coronal linear deviation of 1.40 ± 0.54 mm, and an apical linear deviation of 1.59 ± 0.59 mm.\(^9\) The deviations often occur in the buccolingual direction. In some cases with poor bone quality and bone volume, or cases with limited restorative space, the correct 3D position range of the implant is relatively limited, and a larger deviation indicates a poor prognosis or failure.\(^4\) The specific manufacturing technique, 3D printing device, resin material, and application of preoperative sterilization affect the accuracy of sCAIS.\(^12\) The guide system that is commonly used includes a guide plate, guide sleeve, and handles. The surgical site and method of support could affect the deviation of the implant placed through guided surgery.

### Accuracy of Intraoperative Measuring Guide and Conventional Surgical Guide in Anterior Implant Surgery: A Retrospective Case-Control Study

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**Purpose:** To verify a novel method that improves the accuracy of static computer-aided implant surgery (sCAIS) through intraoperative measurement. **Materials and Methods:** Forty-seven patients were selected for this study, each with a missing tooth or a tooth that required extraction from the anterior area. The patients were divided into the intraoperative measuring guide (MG) and conventional guide (CG) groups. Following the preoperative implant planning, the surgical guides were designed and fabricated. In the MG group, the drill was guided by double-armed zirconia sleeves, and the axial direction of the drill was assessed using the indicator components. The implant was guided using a resin guide tube. In the CG group, the drills were guided using a metal sleeve and handles, and the implants were placed with the guidance of the metal sleeve only. The angular and linear deviations at the entry and apex between the planned and actual implant positions were measured after matching the preoperative and postoperative CBCT data. The independent-samples t test was used to compare the deviation between the MG and CG groups. **Results:** The 3D deviations for the MG group at the entry and apex were 0.67 ± 0.44 mm and 0.93 ± 0.40 mm, respectively. The angular deviation was 2.27 ± 0.96 degrees. Statistical differences were found in the 3D deviation at the entry point and apical position between the MG and CG groups, yielding relatively smaller deviations in the MG group. **Conclusion:** The use of an intraoperative measuring guide could improve the accuracy of implant placement in sCAIS. *Int J Oral Maxillofac Implants* 2022 December 15. doi: 10.11607/jomi.9898. Online ahead of print.

**Keywords:** accuracy evaluation, angular deviation, implant placement, implant surgical guide, intraoperative measurement, linear deviation
surgery using a nonmetal sleeve template as well. Tolerance is present between the handles and the drill. It is difficult to accurately assess whether the implant has a deviation during the operation since the position of the drill is not assessed during sCAIS; therefore, it is not conducive to timely correction. The present study team developed a novel surgical guide for intraoperative measurement to improve the accuracy of implant placement.

Immediate implant placement (IIP) has the advantages of shorter treatment time, fewer surgeries, and a similar survival rate to that of delayed implant placement (DIP); therefore, it is used widely. Chen et al reported that even with the help of a surgical guide, the final implant position in IIP tended to shift facially, indicating that further improvement of the accuracy of sCAIS remains challenging.

This study aimed to (1) verify a novel method that improves the accuracy of sCAIS through intraoperative measurement and (2) compare the accuracy of DIP and IIP with the aid of this intraoperative measuring guide.

MATERIALS AND METHODS

Patient Selection
Forty-seven patients who underwent sCAIS in the anterior area from September 2020 to August 2021 in the West China Hospital of Stomatology enrolled in this study. Thirty-four patients had a missing tooth, and 13 patients each had a tooth indicated for extraction. The selected patients were randomly allocated to the intraoperative measuring guide (MG) group and the conventional guide (CG) group using a random number table.

The inclusion criteria were as follows:

- Adults aged 18 years or older
- Provision of a signed informed consent form
- Good general health
- Sufficient bone tissue for implant placement at each site without any requirement of augmentation
- DIP: a single tooth missing for more than 3 months and ideal implant position with 2-mm buccal bone at the platform
- IIP: requirement of single tooth extraction in the anterior area due to trauma, periodontitis, endodontic or unrestorable caries, type I socket, free of active infection, with adequate quantity of native bone to achieve primary stability
- Patients with sufficient remaining teeth on both sides of the implant area to support the surgical guide

The exclusion criteria were as follows:

- Uncontrolled periodontal disease
- Uncontrolled diabetes, hypertension, and other systemic diseases that would interfere with the implant surgery
- Pregnancy
- Heavy smoking and alcoholism
- Severe bone defects
- Patients unable or unwilling to undergo preoperative and postoperative CBCT scans
- Patients who rejected the treatment plan

This study was approved by the Ethics Committee of the West China Hospital of Stomatology (reference number: WCHSIRB-D-2021-200, registered in chictr.org [registration number: ChiCTR2100051074]). Informed consent was obtained from all patients, and the Strengthening the Reporting of Observational Studies in Epidemiology guidelines were followed during the preparation of the article. One experienced surgeon (H.Y.) performed all the surgeries in this study. This study was conducted in accordance with the Declaration of Helsinki.

The digital information of the patients was comprehensively collected before the surgery. All patients underwent a CBCT examination (J Morita), face and intraoral photograph assessment (90D; Canon), and intraoral scan (TRIOS 3, 3Shape; Figs 1a and 1b). A digital smile design was utilized based on the information provided by the photographs and intraoral scans. A virtual diagnostic wax-up made using exoCAD 3.0 (exoCAD) was exported as a Standard Tessellation Language (STL) file (Fig 1c) and imported into the implant planning software (Bluesky Plan4, Bluesky Bio). After the superimposition with the Digital Imaging and Communications in Medicine (DICOM) file derived from the CBCT scan, the virtual implant was selected from the implant library and placed in the correct 3D position in the bone based on the “restorative-driven” design and biologic-driven concept (Figs 1d and 1e).

During the implant surgery in the MG group, intraoperative measuring guides were used to guide the preparation and placement of the implant. The components include the guide plate, double-armed zirconia sleeves, and indicator components (Fig 2). The double-armed zirconia sleeves with different inner diameters were used in sequence to guide the drills required for implant bed preparation. These sleeves are mass-produced, and their inner diameters match the drills with different diameters in different implant systems, allowing repeated use after sterilization. The two extending ends of the sleeve could be connected with indicator components, which could be used to assess the axial direction of the drills with a measuring ruler with 0.5 mm resolution.
From the perspective of intraoperative measurement, this verification protocol is based on the lever principle, presuming that there is a point on the drill shank corresponding to a point in the bone along the path of the drill and that their deviations relative to the planned implant axis have the same magnitude but opposite direction. Therefore, the deviation occurring in the bone can be symmetrically reflected on the drill shank, facilitating direct measurement of the linear deviation using a ruler in the established coordinate system based on the attached indicators. The distance between the inner wall of the indicator and the planned implant axis is 8.5 mm, and labiopalatal deviations are identified when the measured value differs from the preset value. For verification in the mesiodistal plane, the 43-mm-long ruler is placed against the lateral walls of two indicators, tangent to the drill shank when no mesiodistal deviations occur. The CG group used the sleeve-in-sleeve system (Straumann Guided Surgery, Straumann), utilizing a metal sleeve embedded in the surgical guide and drill handles (Fig 4). The resin guide plate and indicator components were fabricated using a 3D printer (ProJet MJP 3600, 3D Systems). The double-armed zirconia sleeves were milled and sintered using a chairside CAD/CAM machine (AVDS & AGT-S, Aidite).
Surgical Procedure
A 4% articaine solution was used as local infiltration anesthesia after intraoral and extraoral disinfection of the patient. In the IIP cases, the tooth was extracted in a minimally invasive manner, whereas in the DIP cases, a horizontal incision was made on the crest of the alveolar ridge. All sites adopted a minimally invasive approach without opening the flap. The surgical guide was put in place and confirmed to be in close contact with the teeth through the inspection window. In the MG group, a double-armed zirconia sleeve with a 2.2-mm inner diameter was embedded in the guide plate. The implant bed was prepared using a 2.2-mm-diameter pilot drill. After the preparation, the indicator components were connected to the two ends of the zirconia sleeve, and the drill remained in the implant bed. A measuring ruler was used to measure the distance between the indicator component and the center of the drill. The zirconia sleeve was replaced with a sleeve with a larger inner diameter after the axial verification of the drill, and the axial verification for each drill was repeated. After completing the drilling sequence, the resin guide tube guided the placement of implants in the MG group (Fig 5). In the CG group, the drills were guided using adjustable handles; the metal sleeve guided the placement (Fig 6).

Accuracy Evaluation
After implant placement, the postoperative CBCT scan was performed under a lower dose (50 kV, 5 mA) and a smaller field of view (FOV, 50 × 50 mm); the accuracy was analyzed according to preoperative and postoperative CBCT data of the patients. The DICOM format data of preoperative and postoperative CBCT were 3D reconstructed and imported into Geomagic Wrap 2017 (3D Systems) for superimposition. The postoperative jaw and implant were fitted to the preoperative position, and the fitting point was placed in the jaw where the implant was in order to exclude the mandibular position error during the CBCT scan and ensure the precision of implant fitting.

The angle deviation and linear deviation of the implant were used as analysis parameters to evaluate the accuracy of the implant and the guidance of the surgical guide (Fig 7). An angle deviation is defined as the angle of the central axis of the planned implant position and the actual position. Linear deviation includes...
the deviation between the midpoint of the coronal and apical 3D deviations, including its deviation in the 3D direction, depth, and transverse deviation. The 3D deviation is the overall deviation between measurement points, and is the summation of buccolingual, mesiodistal, and depth measurements in the geometric space direction.

Statistical Analyses
All data were analyzed and calculated using the Statistical Package for Social Sciences (SPSS) version 23.0 (SPSS). The independent-samples t test was used to compare the deviation parameters between the MG and CG groups, and two-way analysis of variance was used to analyze the difference between the MG and CG groups in IIP and DIP,
respectively. All reported $P$ values were two-sided, and the level of significance was set at .05.

**RESULTS**

Forty-seven patients were included in this study with 18 DIP and 6 IIP in the MG group and 16 DIP and 7 IIP in the CG group. Adequate primary stability (implant torque > 35 Ncm) was achieved in all implants, and the survival rate of the implants was 100%. The study process is shown in Fig 8.

There were statistically significant differences between the MG and CG groups in the 3D deviation at the entry point (MG: 0.665 ± 0.441 mm, CG: 1.102 ± 0.656 mm, $P = .010$) and the apical position (MG: 0.933 ± 0.401 mm, CG: 1.343 ± 0.659 mm, $P = .015$). Furthermore, a greater buccolingual deviation was observed in the CG group at the apical position (MG: 0.469 ± 0.358 mm, CG: 0.744 ± 0.496 mm, $P = .034$). There was no statistical difference between the MG and CG groups in the angular deviation (Table 1). When analyzing the results, there were 18 DIP and 6 IIP in the MG group and 16 DIP and 7 IIP in the CG group. In the case of DIP in the MG and CG groups, a statistical difference was found in the coronal (MG: 0.647 ± 0.495 mm, CG: 1.209 ± 0.682 mm, $P = .026$) and apical 3D deviations (MG: 0.885 ± 0.431 mm, CG: 1.406 ± 0.698 mm, $P = .039$). Furthermore, a statistically significant difference was found in the apical buccolingual deviation in DIP in the MG and CG groups (MG: 0.401 ± 0.337 mm, CG: 0.812 ± 0.521 mm, $P = .037$). There was no statistical difference in the angle, depth, and mesiodistal deviation, and no statistical difference was found in DIP and IIP in either group (Fig 9).

**DISCUSSION**

Proper positioning of the implant is critical to avoid esthetic complications, which could minimize the resorption of the buccal bone; maintain the correct distance between the adjacent teeth/implants to preserve
adequate blood supply; maintain healthy hard and soft tissues; and allow a correct prosthetic phase. sCAIS has gained popularity among clinicians due to its increased accuracy of implant placement. However, it is difficult to determine whether a deviation is introduced during the implant bed preparation. The appropriate time to correct any errors will often be missed if only postoperative CBCT is performed to determine whether the implantation is accurate. The present study has introduced a method of intraoperative verification to solve this problem. Certain points should be considered while using sCAIS with MG. The relative position of the drill and guide sleeve is measured during the operation, and this measurement is based on the guide. This is to verify the accuracy of the guide system, and the correction is performed to achieve the maximum guiding accuracy of the guide. Thus, it is critical to ensure that the guide plate is accurately positioned. In addition, it is necessary to remove the guide plate to measure the positional relationship between the drill and adjacent natural tooth to evaluate the actual intraoral position of the drill according to the preoperative design and correct the deviation in time because of the systematic errors of the guide plate itself. These corrections have different meanings. The first correction verifies the guiding accuracy with the guide, and the correction achieves the maximum accuracy. The latter is the actual measurement of the clinical situation, which can be found as the deviation of the guide results from the actual demand.

This study aimed to introduce the use of a new intraoperative measuring implant guide and compare the accuracy of IIP and DIP with the aid of this intraoperative measuring guide and conventional guide by analyzing the preoperatively planned position and actual postoperative implant position. Studies have reported that using a metal sleeve in sCAIS can result in a greater angular deviation than sCAIS without using a metal sleeve. El Kholy et al reported that the drilling key height influenced the accuracy of implant placement. The zirconia sleeve used in the MG group exceeds 1 mm above the resin tube, consistent with a drill key height.

Table 1 Deviation Between Planned and Actual Implant Positions

<table>
<thead>
<tr>
<th>Measurement</th>
<th>MG group (n = 24)</th>
<th>CG group (n = 23)</th>
<th>Differences between MG and CG</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angular deviation (deg)</td>
<td>2.267 ± 0.958</td>
<td>2.511 ± 1.186</td>
<td>0.244 ± 0.314</td>
<td>0.441</td>
</tr>
<tr>
<td>Deviation at the coronal position (mm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3D</td>
<td>0.665 ± 0.441</td>
<td>1.102 ± 0.656</td>
<td>0.437 ± 0.162</td>
<td>0.010*</td>
</tr>
<tr>
<td>Mesiodistal</td>
<td>0.240 ± 0.191</td>
<td>0.238 ± 0.238</td>
<td>0.003 ± 0.063</td>
<td>0.966</td>
</tr>
<tr>
<td>Buccolingual</td>
<td>0.317 ± 0.248</td>
<td>0.510 ± 0.447</td>
<td>0.194 ± 0.106</td>
<td>0.077</td>
</tr>
<tr>
<td>Depth</td>
<td>0.477 ± 0.416</td>
<td>0.734 ± 0.703</td>
<td>0.257 ± 0.170</td>
<td>0.138</td>
</tr>
<tr>
<td>Deviation at the apical position (mm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3D</td>
<td>0.933 ± 0.401</td>
<td>1.343 ± 0.659</td>
<td>0.410 ± 0.160</td>
<td>0.015*</td>
</tr>
<tr>
<td>Mesiodistal</td>
<td>0.465 ± 0.273</td>
<td>0.439 ± 0.346</td>
<td>0.026 ± 0.091</td>
<td>0.779</td>
</tr>
<tr>
<td>Buccolingual</td>
<td>0.469 ± 0.358</td>
<td>0.744 ± 0.496</td>
<td>0.275 ± 0.126</td>
<td>0.034*</td>
</tr>
<tr>
<td>Depth</td>
<td>0.479 ± 0.414</td>
<td>0.739 ± 0.710</td>
<td>0.260 ± 0.171</td>
<td>0.136</td>
</tr>
</tbody>
</table>

SD = standard deviation; min = minimum; max = maximum; *P < .05.

Fig 8 Flow diagram of the study design.
of 1 mm in the CG group. Moreover, they have the same guidance height of 6 mm.

The accuracy of sCAIS was reported to be related to the experience of the operator\textsuperscript{23}; however, the results show that the mean 3D deviation, with the aid of an intraoperative measuring guide, was 0.665 ± 0.441 mm at the entry point and 0.933 ± 0.401 mm at the apical position, and the angular deviation was 2.267 ± 0.958 degrees. The mean 3D deviation, with the use of a conventional guide, was 1.102 ± 0.656 mm at the entry point and 1.343 ± 0.659 mm at the apical position, and the angular deviation was 2.511 ± 1.186 degrees with the conventional guide, which was comparable to the results of previous studies.\textsuperscript{6,9,24,25} Deviations at the coronal and apical points in the MG group showed a decreasing trend compared with the CG group, and three of the nine items measured were statistically significant, including 3D deviation at the coronal aspect and 3D and buccolingual deviations at the apical aspect, demonstrating that MG facilitates deviation control intraoperatively, especially for the buccal deviation at the apex. A larger sample size is needed in the future. In addition, deviations in the mesiodistal direction are almost equal to or lower than those in the buccolingual direction in both MG and CG groups, implying that MG and CG have the same capacity for restricting the mesiodistal position of the drill and the implant driver. From another point of view, the result reveals that a more buccal position of the apex is more likely under the guidance of CG,\textsuperscript{26} which may result in excessive preparation of the bone around the implant apex and even perforation.\textsuperscript{4,27} The improvement of the ability of MG to control the buccal deviation can help reduce the above risks. A statistical difference was found between the MG and CG groups in DIP in the coronal and apical 3D deviations. Furthermore, a statistical difference was found in the apical buccolingual deviation in DIP in the MG and CG groups, but not in the apical buccolingual deviation in IIP in the MG and CG groups, indicating that the buccolingual deviations caused by anatomical conditions in IIP are difficult to correct. The angular deviation of the MG group seemed to be lower; however, there was no statistical difference in angular, depth, and mesiodistal deviation. No statistical difference was found between DIP and IIP in MG or CG. The indicator component is mainly used to measure the buccolingual axis of the drill. Statistical differences were found in the apical buccolingual deviation in the MG and CG groups, which indicates that the intraoperative measuring guide has advantages in the buccolingual axial control of the apex of the implant.

Fig 9  The deviation parameter bar plots of the intraoperative measuring guide and conventional guide groups in delayed implant placement and immediate implant placement, respectively. *P < .05.
The new protocol comprises verification steps that are absent in the conventional surgical guide protocol. These steps increase the operation time by a few minutes, and introducing double-armed zirconia sleeves increases the cost. However, these additional steps are not complex and do not require special training. Also, the protocol does not lead to a significant increase in the cost, as the sleeves are mass-produced and their inner diameters match drills with different diameters in different implant systems, allowing repeated use after sterilization.

The present study has some limitations. First, the surgeon was aware of the type of guide being used. Thus, there may be a certain degree of subjective bias. Second, the surgeon's manual correction after intraoperative measurement cannot be quantified, and there may be a large difference. Third, fewer cases of immediate implantation were included, which may have affected the statistical results between the DIP and IIP groups.

CONCLUSIONS

Within the limitations of this study, the use of the intraoperative measuring guide could improve the accuracy of implant placement in sCAIS.

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