Accuracy of surgical positioning of orthodontic miniscrews with a computer-aided design and manufacturing template

Hong Liu, Dong-xu Liu, Guangchun Wang, Chun-ling Wang, and Zhen Zhao
Jinan, China

Introduction: Our objective was to enable accurate miniscrew placement after preoperative simulation. We developed a new template for miniscrew placement and evaluated its accuracy. Methods: Eleven patients who had bimaxillary protrusion were scanned with computed tomography. The 3-dimensional computed tomography data were used to produce, with stereolithography apparatus, a template for accurate miniscrew placement. The interradicular space available for miniscrew placement was calculated in the 3-dimensional images. Postoperative computed tomography images were matched with preoperative images to calculate the deviations between the planned and actual placements. Results: The distance for placement of a miniscrew between 2 roots was 4.12 mm (SD, 0.25 mm; range, 3.7-4.5 mm). The placed miniscrews showed an average angular deviation of 1.2° (SD, 0.43°; range, 0.6°-2.41°) compared with the plan, whereas the mean linear distomesial deviation was 0.42 mm (SD, 0.13 mm; range, 0.15-0.6 mm) at the tip. Conclusions: The proposed template has high accuracy and will be especially useful for patients who require precise miniscrew placement. (Am J Orthod Dentofacial Orthop 2010;137:728.e1-728.e10)

Miniscrews have been used for absolute anchorage in orthodontics for a long time.1,2 Miniscrews are always placed in alveolar bone between the first molar and the second premolar, and the placement angle is always 30° (the long axis of the miniscrew and the tooth axis) in the maxilla and 20° in the mandible.3 However, the high failure rates of miniscrews troubles orthodontists. According to previous articles, the rates of failure are about 11% to 30.4%.1,2,4 Placing a miniscrew in the limited space between the roots of the second premolar and the first molar causes some risk of injury to important anatomic structures.4 Safe and optimal miniscrew stabilization requires ideal placement point and trajectory. Improper screw placement can lead to neurovascular damage or suboptimal biomechanical stabilization.5-7 To achieve precise and safe placement of miniscrews in interradicular sites, several methods have been developed, but they cannot guarantee precise placement.8-14 A controllable method for miniscrew placement and direction is important for orthodontists.

Computed tomography (CT), 3-dimensional (3D) software, and stereolithography apparatus (SLA) (Xi’an Jiaotong University, Xi’an, China) have been widely used in oral medicine.9,15-23 CT has been used for measurement of interradicular space for miniscrews and assessment of their position. The 3D software helps to render objects from the CT images for diagnosis and treatment planning. Computer-aided design and computer-aided manufacturing (CAD/CAM) technology has been used in dental restorations and implantology.24-26 The CAD/CAM template for implants has been accepted and used widely, and gives us another method to aid in achieving controllable miniscrew placement. In this article, the CAD/CAM template for orthodontic miniscrews is introduced, and its accuracy is assessed.

MATERIAL AND METHODS

Materialise’s interactive medical image control system (MIMICS) and Magics (both, Materialise, Leuven, Belgium) are both widely used medical software programs. The miniscrew template described in this article was designed with these tools.
MIMICS is an interactive tool for the visualization and segmentation of CT and magnetic resonance images and the 3D rendering of objects. Therefore, in medicine, MIMICS can be used for diagnosis, operation planning, and rehearsal purposes. A flexible interface to rapid prototyping systems is included for building distinctive segmentation objects. Magics is companion software to MIMICS; the user can further process the 3D model (stereolithography [STL] file) that is created in MIMICS.

Stereolithography apparatus (SLA) is the process of using photosensitive resins cured by a laser that traces the parts across sectional geometry layer by layer. SLA produces accurate models with various materials. We used a resin (SOMOS 11120 photosensitive resin, DSM, Elgin, IL).

Eleven patients with bimaxillary protrusion agreed to have their 4 first premolars extracted; 34 miniscrews (Beici Medical Company, Ningbo, China; Fig 1) were planned to provide absolute anchorage. The miniscrews were placed in the interradicular area between the second premolar and the first molar. Six patients received 4 miniscrews, and 5 patients had miniscrews placed in the maxilla only.

The CAD/CAM template for the miniscrews in this study was designed based on the CT data and fabricated by the SLA. After preparing mounted diagnostic casts with fully extended vestibular borders of the jaws, the radiographic templates were fabricated with the vacuum-formed technique (Fig 2), and the patients and the radiographic template were scanned before the procedure with the double-scan technique17 (the first scan is of the patient with the radiographic template in place, and the second scan is of the radiographic template only). The 3D virtual models of the teeth and the 2 jaws were reconstructed based on the CT data in the

![Fig 1. A, Miniscrew (diameter, 1.6 mm; length, 11 mm; pitch, 0.2 mm); B, self-drilling driver.](image1)

![Fig 2. A, Template with buccal and lingual vestibular border extensions was fabricated on the stone cast with the vacuum-formed technique; B, radiopaque markers were placed on the template; C and D, template was adjusted in the mouth to ensure proper seating.](image2)
MIMICS software (Fig 3, A-C) by superimposing the 2 sets of scans (the osseous tissues and the radiographic template) with radiographic markers as reference points (Fig 3, D). The virtual miniscrews were placed in safe and optimal positions when the roots of teeth were visualized (Fig 4, A), and the placement site and angle were determined. The drill template was designed with the radiographic guide and the 3D information of the planned drill paths (Fig 4, B-D), and the stereolithography template was fabricated with a CAD/CAM procedure (the rapid prototyping [RP] apparatus was manufactured by Xi’an Jiaotong University); the template is shown in Figure 4, E. To improve the intensity of the template, the positioning sleeves were cemented in the surgical template (Fig 4, F). When the bone-teeth and radiographic templates were reconstructed, the thresholds were chosen carefully, and the thickness of the radiographic template was compared with the stereolithography one to assess the reliability of the threshold and the accuracy of the RP.

When the 3D models of the teeth and the 2 jaws were reconstructed, we evaluated the osseous tissues in relation to the position of the teeth by merging the independent data, and the virtual miniscrews (cylinders) were placed in the ideal position (proper placement site and orientation). When the position for the miniscrew was determined (Fig 5, A), a plane was created along the cylinder (Fig 5, B). The distance between the 2 roots for the miniscrew was measured. At this plane, the minimum distance between the 2 roots was measured. As we know, the periodontal ligament is about 0.15 to 0.38 mm thick on average, and the diameter of the miniscrew in this study was 1.6 mm. The virtual screw was placed in the midline of the 2 roots, and the safe deviation for the miniscrew could be calculated by the formula, \( C = \frac{A}{2} - B - 0.4 \) mm, where \( A \) is the interradicular distance, \( B \) is the radius of the miniscrew, and \( C \) is the safe deviation. The periodontal ligament was assumed to be 0.4 mm thick in this study for safe placement. Thus, the allowed deviation for the miniscrew was obtained and used as the control for assessment of the accuracy of the template.

After a local anesthetic was given, the surgical template was placed intraorally. The seating of the template should be confirmed, and the surgical template should be held in place by the patient’s bite force. Once it was seated, the patient was asked to bite the template to expose the surgical sites of the guide; then the self-drilling miniscrews were placed with a screwdriver (Fig 6).

The surgical procedures were performed uneventfully, and the patients were scanned with CT again. The postoperative 3D models of the teeth, maxillae, mandibles, and miniscrews were reconstructed and registered with the preoperative 3D models by using the same anatomic sites as landmark points (Fig 7). The point registration easily moved an STL image to a certain location. This was done by placing 4 sets of landmark points on the STL images, 3D objects, and images. MIMICS then calculated the transformation matrix for the best fit between the start and end points.
and applied that transformation matrix on the selected STL images. Because of the radiographic template on the occlusal surface, the mandible’s position on the before and after CT images was different, so the mandible and maxilla must be registered separately (Fig 7). After point registration, the STL registration was performed to register STL images on masks to improve the accuracy of registration. Registrations were performed 3 times in 2 weeks, and we chose the best one for measurements of this study (Fig 8).

To measure the deviation of the center position of the miniscrews from the planned position (cylinders) in 3 dimensions, the new 3D coordinate was adjusted and defined at the apex of the virtual miniscrew in Magics (Fig 9). The x, y, and z axes were defined: the x-axis represents the distomesial position, the y-axis represents the vertical position, and the z-axis represents the buccopalatal position. The 3D deviation of the actual miniscrew was calculated at the apex and the placement site (Fig 9). The x, y, and z values at the apex represented the deviation of the actual miniscrew. In this way, the deviation was evaluated in 3 directions, and the distomesial position (x-axis) was more important for the security of the miniscrew. In this study, we mainly focused on assessing this axis. As for angle deviations, they were hard to evaluate, since the angle between the actual miniscrew and the simulated one showed a twisted relationship. Therefore, in this study, both central axes were projected to the mesiodistal axis, and the deviation of the angle between them was calculated with the formula, \[ \theta = \tan^{-1} \left( \frac{b - a}{c} \right), \]

where \(a\) is the deviation at the tail, \(b\) is the deviation at the head, and \(c\) is the length of the miniscrew in the bone. At the placement sites, there was little deviation, so the deviation there was measured with linear CT measurements instead of 3D assessment.

**Statistical analysis**

All measurements were repeated for 15 randomly selected subjects, with a 1-week interval, to assess intra-examiner reliability, which showed no statistical
differences ($P > 0.05$) from the paired $t$ test. The method error according to Dahlberg’s formula was 93.2. The means and standard deviations of the measurements were calculated. To compare the template deviation with the allowed deviation, a paired $t$ test was used, and 2-way analysis of variance (ANOVA) was used to analyze the deviations in 3 direction (SPSS for Windows, version 11.5, SPSS, Chicago, Ill). $P < 0.05$ was considered to be statistically significant.

RESULTS

The interradicular safe zones for miniscrews in the 11 patients ranged from 3.7 to 4.5 mm, with an average of $4.12 \pm 0.247$ mm (mean $\pm$ SD). The allowed deviation ranged from 0.65 to 1.05 mm, with an average of $0.86 \pm 0.125$ mm (mean $\pm$ SD).

The templates were adapted to the patients in a satisfactory and stable manner. All miniscrews were placed smoothly without problems. Some miniscrews did not
touch the adjacent roots (Fig 8, B). The accuracy of drilling, and the deviations of the positions and angles of the actual miniscrew from the simulations, were examined in 3 directions.

The position deviations at the distomesial, vertical, and buccopalatal directions were 0.42 ± 0.13, 0.47 ± 0.12, and 0.59 ± 0.26 mm at the tip, respectively, and 0.10 ± 0.012 mm at the placement sites. The miniscrew deviations of the angles from the planned position at the distomesial, vertical, and buccopalatal directions were 1.2° ± 0.43°, 1.3° ± 0.41°, and 1.6° ± 0.79°, respectively. No statistically significant differences were observed between the deviations at the distomesial and vertical directions. The buccopalatal deviation was greater than the other 2 directions, with a significant difference (Fig 10, A). In this study, the deviations at the vertical and buccopalatal directions did not influence the security of miniscrew; we focused mainly on the distomesial deviations. All deviations of the miniscrews were in the safe zone, and each actual deviation was smaller than the allowed one. As seen in Figure 10, the deviation of the template guide group was significantly smaller than that of the control group (allowed deviation); the difference was statistically significant ($P < 0.05$).

**DISCUSSION**

CT is an important diagnostic tool for the craniofacial region and is used for many applications including the study of its various components, growth, developmental anomalies, impacted teeth, management of maxillofacial trauma, treatment planning for orthognathic and reconstructive surgery, bone grafting, distraction osteogenesis, and dental implantology. Qualitative and quantitative findings and measurements from CT techniques are accurate and reproducible, and offer greater and more reliable assessment of deeper anatomic structures than systems involving biplanar radiography.

Yet there are many reports on the use of CT to measure interradicular spaces for placement of miniscrews. Poggio et al,27 Park,31 and Carano et al32 measured the distances between the roots of adjacent teeth using different methods; they all demonstrated that interradicular spaces for miniscrews are limited, and miniscrews must be placed accurately. In those studies, the measurements of interradicular spaces for miniscrews were based on 2-dimensional (2D) images (slices) of the CT scans. However, miniscrews are always placed with an inclined angle, obviously limiting measurement of the 2D images.3 In this study, the 3D interpolation technique that transforms 2D images (slices) into 3D models was used; with 3D software, the simulated miniscrew can be placed in an ideal position. Along the axis of the miniscrew, the mesiodistal distance between adjacent roots can be measured individually, and the safe zone for the miniscrew was calculated. By using this method, the safe zone is more reliable, and the mesiodistal distance between the 2 roots was shown to be limited for miniscrew placement (Fig 10, B).
The CAD/CAM surgical template has been widely used for implants and prostheses, and its accuracy had been shown in many studies.\textsuperscript{24-29} Similar to implants, miniscrews placed in limited interradicular spaces need high accuracy. The CAD/CAM template gives orthodontists another safe way to place miniscrews. Accuracy and security were evaluated in this study, and it was demonstrated that the surgical template can place the miniscrew in the safe zone with limited deviation. Many reasons were proposed to account for the deviations observed in the template evaluation, as follows.

The stability and inherent support of the template is surely a crucial factor.\textsuperscript{24,28} In this study, the template was supported by 2 surfaces—occusal teeth and buccal mucosa—and the bite force on the template...
provided support to keep it stable. So the interocclusal record with a rigid vinyl polysiloxane (Access Blue, Centrix Dental, Shelton, Conn) for the patient to hold the radiographic template in position during the CT scan and prevent movement could help hold the CAD/CAM template in the right position.

The size of the 3D model depends on the threshold value, which is a specific density on a slice image that separates the organ of interest and other regions. Therefore, it is important to select the proper threshold value. An inadequate threshold value of the radiographic template affected the accuracy of the STL model greatly. In this study, the maxillary, mandibular, teeth, and radiographic templates were reconstructed with different threshold values (387-1988HU, 415-1988HU, 1430-2850HU, and -630-690HU in Mimics). When the 3D models are reconstructed, the size must be compared to the actual one, so that the proper threshold can be obtained.

During the procedure of template design, the registration was based on the landmarks that were added on the radiographic template (Fig 2, A and B). The accuracy was assessed after the registration of the preoperative and postoperative models. In this study, the combination of 2 registration methods improved the accuracy. The before and after models were the same, but the miniscrews and the STL images’ registrations achieved better results. Repeated registrations, choosing the best registration by visual inspection, and identifying corresponding landmarks ensured the accuracy of the registrations. The registrations were performed carefully, and the results were satisfactory (Figs 8 and 9).

RP is a relatively new technology that produces physical models by selectively solidifying ultraviolet-sensitive liquid resin with a laser beam. Choi et al.29 investigated errors generated during the production of medical RP models and showed that the absolute mean deviation between the original and RP models over the 16 linear measurements was 0.56% ± 0.39%; this had little influence on the accuracy of the template. In our study, the thickness of the template was measured, and the mean deviation was about 0.87% ± 0.45%, so that the RP deviation caused little change in the deviation of miniscrew placement.

The template in the study was designed with CAD/CAM implant template methods, but there are still some differences. A miniscrew is placed in the buccopalatal direction and an implant is in the vertical direction, so the shape and the support methods are different with the implant template. To keep the miniscrew stable, at least 1 anchor pin through the alveolar process is used for more support of the implant template. The mini-screw template remains stable from the patient’s bite force. There are scale markers at the head of the drills for implant depth control, and we also put a marker on the screwdriver to control the depth of the miniscrews in this study; 3D control of miniscrew was achieved even though the buccopalatal deviation was greater than in the other 2 directions (Fig 10, A).

The template still has some deficiencies, and improvement of its elaborate design and further studies should be performed to evaluate the reliability, validity, and global applicability of stereolithographic surgical guides for miniscrews. The high radiation of a CT scan and the high cost limit the broad use of this...
CAD/CAM guide for miniscrews. But this study showed a CAD/CAM guide system constructed for orthodontic miniscrews similar to prosthetic implant guides and verified that the accuracy of the CAD/CAM template was enough for miniscrew control and safe placement.

CONCLUSIONS

Within the limits of this study, we presented an accuracy evaluation of the CAD/CAM template for miniscrews, and the registrations of the 3D models reconstructed with the preoperative and postoperative CT data were validated. The average measured deviations of the miniscrews were in the safe range. These results verified the template’s accuracy and security. The template, manufactured with the Nobel method, can provide safe placement for miniscrews.

We thank Professor Guang-chun Wang for his assistance.

REFERENCES


