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Original Article

# Effects of an augmented reality aided system on the placement precision of orthodontic miniscrews: A pilot study

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Orthodontics;
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Mesiodistal position;
Angle

**Abstract** *Background/purpose:* Augmented reality (AR) is gaining popularity in medical applications, which may aid clinicians in achieving improved clinical outcomes. The purpose of this study was to determine the positional and angle errors of orthodontic miniscrew placement by using a self-developed AR aided system.
*Materials and methods:* Cone beam computed tomography (CBCT) and patient printed models were used in in vitro experiments. The participants were divided into a control group and an AR group, in which traditional orthodontic methods and the AR-aided system were used respectively. After the information obtained from the CBCT images and navigation system was combined on the display device, the AR-aided system indicated the planned miniscrew position to guide the clinicians during the placement of miniscrews. Both methods were compared by a senior and a junior dentist, and the position and angle of miniscrew placement were statistically analyzed using Wilcoxon's signed-rank and Mann—Whitney U tests.
*Results:* When the AR-aided system was used, the accuracy of miniscrew placement in the mesiodistal position considerably increased (83%) when the procedure was performed by a senior clinician. In addition, the accuracy of miniscrew placement in the mesiodistal position and the angle of miniscrew placement considerably increased by approximately 67% and 72%, respectively, when the procedure was performed by a junior clinician. The position error of miniscrew placement was smaller for the junior clinician when the AR-aided system was used than for the senior clinician.
*Conclusion:* The AR-aided system improved the accuracy of miniscrew placement regardless of the clinician's level of experience.

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## Introduction

Miniscrews, also known as orthodontic implants, provide intraoral skeletal anchorage through an advantageously simple treatment procedure and does not require much patient compliance during orthodontic treatment. During the placement of miniscrews, certain anatomical structures should be avoided, such as the adjacent dental roots. The traditional process of miniscrew placement involves only palpation by the clinician while consulting planar X-rays, such as panoramic or periapical films. However, this procedure is inaccurate[1] and may reduce the rate of success of miniscrew placement.[2—4] According to some studies, the root contact of miniscrews may result in irreversible damage, such as root resorption or ankylosis.[5—7]

Surgical guides have been developed to solve the problem of miniscrew placement positioning.[8—10] Bae et al.[11] reported that the positioning errors in miniscrew placement involved a mean angular deviation of 3.14° and mean coronal and apical deviations of 0.73 mm after using surgical guides. Although surgical guides can considerably improve the positioning accuracy of miniscrew placement, they are rarely used by clinicians because of their additional cost and complicated procedure. Augmented reality (AR) may help clinicians in achieving improved medical outcomes, for example, determining the safe area or angle for pedicle screw placement during orthopedic surgery.[12—14] Many physicians have used AR in facial surgery to simulate the procedure before orthognathic surgery.[15—17] This is because AR can help physicians to not only identify anatomical structures (e.g., the mandibular canal), bone quality, and root location during surgery but also directly focus on the region of interest, which is otherwise covered by a surgical guide. It also gives them the advantage of a free-hand system, which allows them to "feel" bone penetration. In 2019, Ma et al.[18] used an AR-aided system for dental implant placement. They reported average angle and distance differences of 4.03° and 1.25 mm, respectively, in the AR group and 6.10° and 1.63 mm, respectively, in the control group, indicating that the implant placement error may have been effectively reduced in the AR group.

Although many studies have explored the use of the increasingly popular AR technology in dentistry and dental implants,[19] no study has investigated the potential of AR in orthodontic miniscrew placement. Therefore, the purpose of this study was to develop an AR-aided system for orthodontic miniscrew placement and compare its accuracy with that of the traditional free-hand method. The outcome differences of the AR-aided system between orthodontic clinicians with varying levels of experience were also evaluated.

## Materials and methods

### Digital planning

Cone beam computed tomography (CBCT) images of one patient (Fig. 1) were selected from the China Medical University Hospital database. Ethics approval was obtained from the institutional review board of the hospital (approval no. CMUH108-REC2-183). The inclusion criteria were being aged above 20 and having both full-skull CBCT images and plaster models available after orthodontic

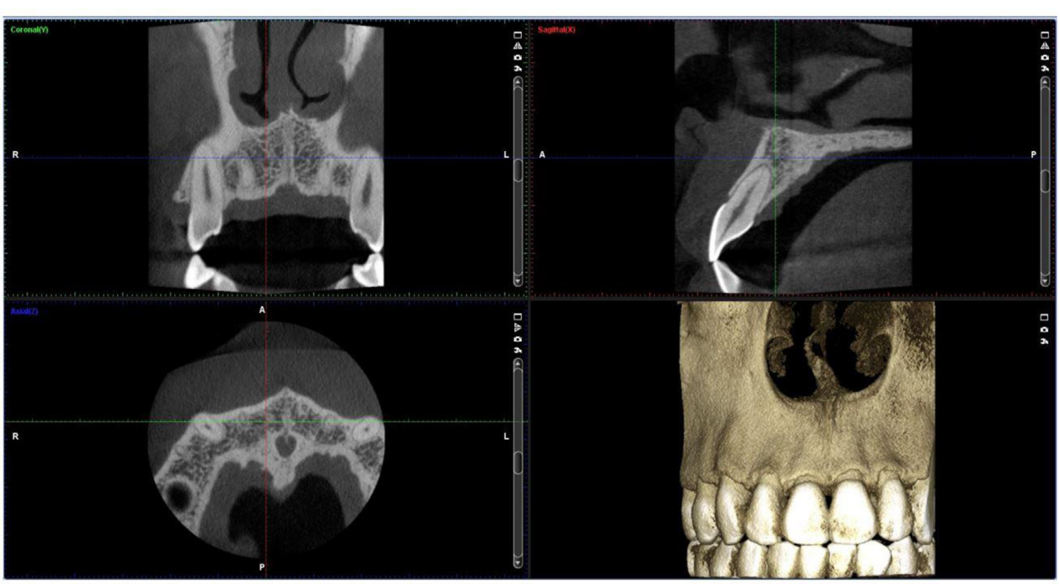

**Figure 1** CBCT images of a patient: frontal (top left), horizontal (bottom left), sagittal (top right), and 3D (bottom right) views.

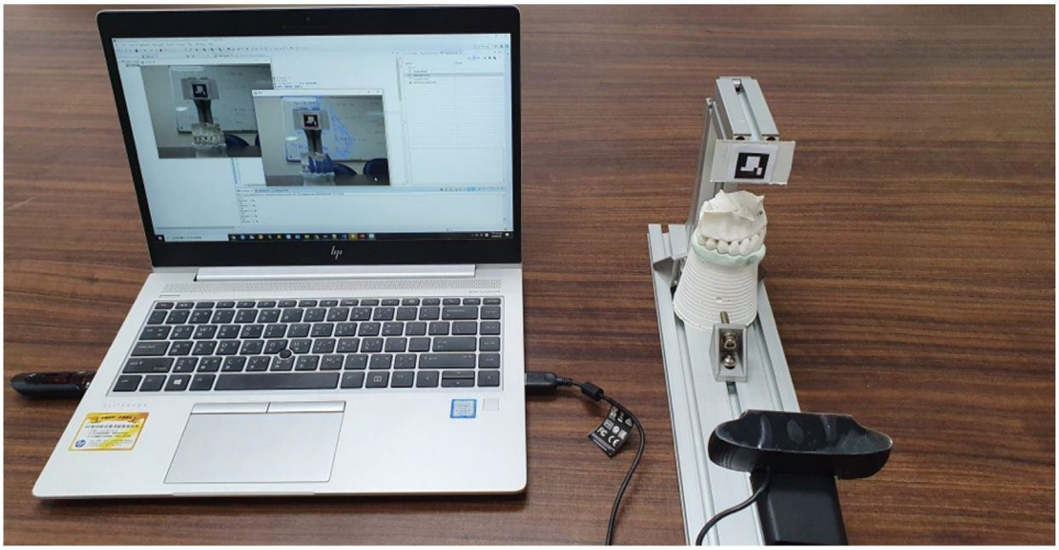

**Figure 2** Augmented reality (AR)-aided system and its equipment, including ArUco marker technology, a camera, and a 3D-printed teeth model.

treatment. The exclusion criteria were missing teeth, dentures, prostheses, impacted wisdom teeth, intrabone or any radiographic lesions, or fractures or bone trauma above the neck.

A miniscrew (Kenko's S&E Orthodontic Miniscrew, BOMEi, Taoyuan City, Taiwan) measuring 8.0 mm in length and 1.5 mm in width was virtually placed on a CBCT image. The planned position of the miniscrew was between the two upper central incisors, with the apex of the miniscrew at the midpoint of two roots. The angle was set to be perpendicular to the bone surface, and the depth was set to 9.0 mm from the bone surface.

## Augmented reality-aided system

The AR-aided system and equipment (Fig. 2) used in this study were developed by us and the Service System Technology Center of the Industrial Technology Research Institute of Taiwan. This system uses computer vision technology to identify teeth by using ArUco markers, and then it superimposes them with a 3D-printed teeth model to aid clinicians in placing miniscrews. After a 3D stereolithographic model was constructed from the patient's CBCT images, the aforementioned 3D-printed model was developed using a light-curing 3D printer (Objet500 Connex3; Stratasys, Eden Prairie, MN, USA) with VeroWhitePlus (Stratasys) resin.

Fig. 3 depicts the workflow of the use of ArUco marker technology and program execution. This technology superimposes augmented information according to the relative location of each identified marker. To confirm position accuracy, the system displays the tooth crown profile by using augmented information, thereby allowing the clinician to confirm any size discrepancies between the AR image and the actual tooth. In this study, the experiments were conducted only after double confirmation.

Once an ArUco marker was detected, a Logitech C922 Prostream Web camera (Logitech, Lausanne, Switzerland) was used to capture the image, and the overlapping image was then displayed on a screen (Fig. 3). After the camera angle was set at 45°, which is the standard visual angle used by clinicians while placing miniscrews, CBCT data were processed using medical imaging software (Mimics v.14; Materialise, Leuven, Belgium) to create 3D teeth models and plan the position of the miniscrew (Fig. 3).

## In vitro experiments

Two clinicians with different levels of experience conducted the *in vitro* experiments. The senior clinician had five years of experience and had placed more than 200 miniscrews, and the junior clinician had less than 1 year of experience and had never placed any miniscrews. Each clinician placed 18 miniscrews by using the traditional method (control group) and 18 miniscrews by using the AR-aided system (AR group).

After miniscrew placement, each model was scanned using CBCT. Three points were then designated on the images, and the preoperative and postoperative images were superimposed. The coronal position of the planned miniscrew represented the coordinate origin, and the *x*-, *y*-, and *z*-axes represented the front and rear (anteroposterior), mesiodistal, and top-bottom directions, respectively.

## Definition of position and angle differences

After all the data were collected, the differences between the planned and actual miniscrew placement at the coronal and apical positions were measured. The angle differences on the *xy* plane between the planned and actual miniscrew placement were also measured (Fig. 4). The 3D angle data were then calculated using the following formula:

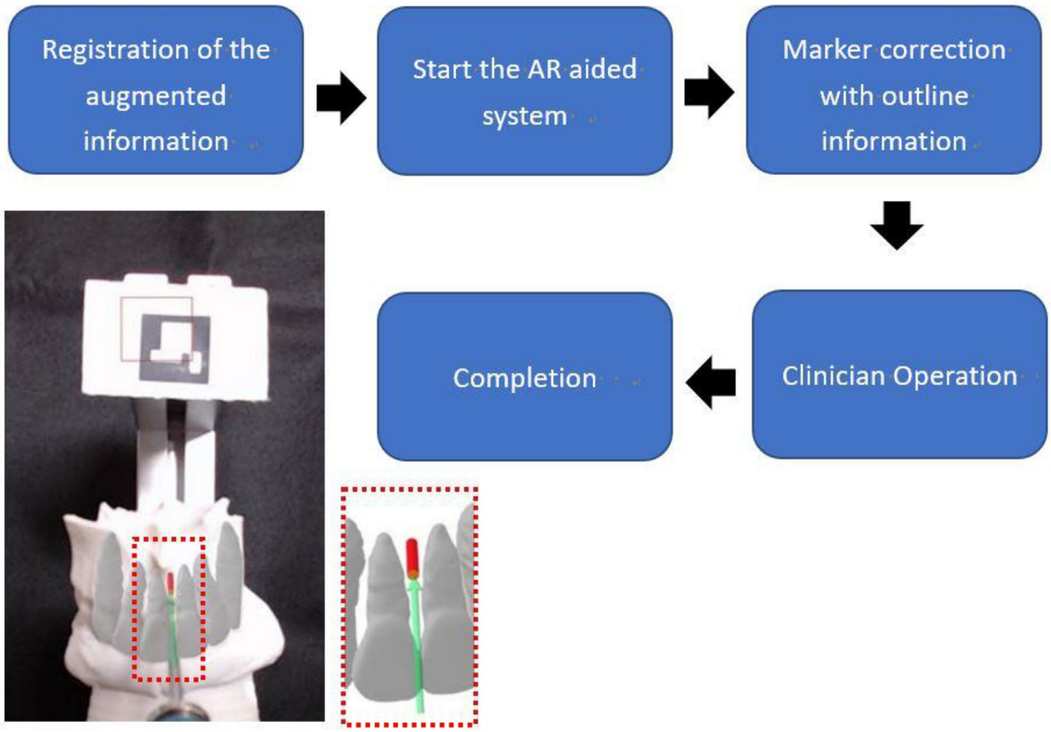


**Figure 3** Workflow of the augmented reality (AR)-aided system during orthodontic miniscrew placement. The green arrow indicates the insertion path for the miniscrew. Augmented reality image superimposed on a screen after an ArUco marker was detected using a camera.

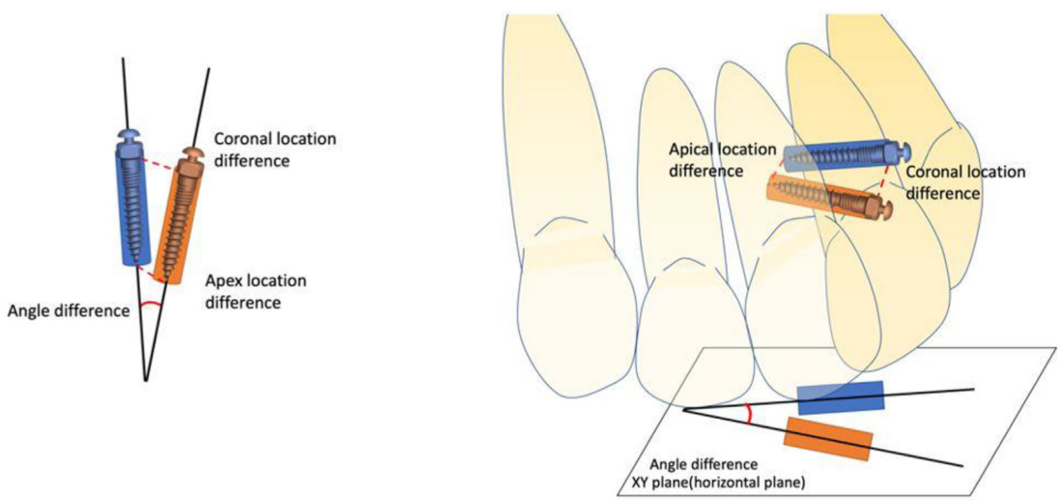


**Figure 4** Location and angle differences of orthodontic miniscrews. The blue and orange colors represent the optimal and actual positions, respectively, of the orthodontic miniscrews.

$$\cos\theta = \frac{x_1x_2 + y_1y_2 + z_1z_2}{\sqrt{x_1^2 + y_1^2 + z_1^2} \times \sqrt{x_2^2 + y_2^2 + z_2^2}}$$

For statistical analyses, Wilcoxon's signed-rank test was used to compare the measured outcomes of each clinician in the control and AR groups. The Mann—Whitney *U* test was then used to compare the data of the senior and junior clinicians. Statistical significance was set at $P < 0.05$. All statistical analyses were performed using MedCalc v.19.0 for Windows (MedCalc Software, Ostend, Belgium).

## Results

### Comparison between the control and AR groups for the senior clinician

For the majority of the variables, no considerable differences were observed in the position and angle between the control and AR groups. When the plane was subdivided into different coaxial directions, a substantial improvement in accuracy was observed on the *y*-axis (mesiodistal direction;

**Table 1** Comparison of the position and angle errors of miniscrew placement between the traditional method (control) and augmented reality (AR)-aided system when performed by a senior clinician.

| | | Control med | Control min | Control max | Control IQR | AR med | AR min | AR max | AR IQR | *P* |
|---|---|---|---|---|---|---|---|---|---|---|
| Apex (mm) | Total | 1.35 | 0.43 | 1.8 | 0.81 | 1.01 | 0.66 | 1.55 | 0.47 | |
| | dX | 0.6 | 0.01 | 1.06 | 0.4 | 0.51 | 0.15 | 0.7 | 0.37 | |
| | dY | 0.67 | 0.01 | 0.96 | 0.29 | 0.11 | 0 | 0.36 | 0.1 | * |
| | dZ | 0.82 | 0.28 | 1.32 | 0.76 | 0.71 | 0.44 | 1.51 | 0.76 | |
| Coronal (mm) | Total | 0.96 | 0.67 | 1.24 | 0.43 | 0.68 | 0.47 | 1.17 | 0.49 | |
| | dX | 0.61 | 0.01 | 0.72 | 0.43 | 0.55 | 0.28 | 1.12 | 0.58 | |
| | dY | 0.56 | 0.06 | 0.96 | 0.57 | 0.19 | 0.04 | 0.42 | 0.22 | * |
| | dZ | 0.66 | 0.02 | 0.8 | 0.66 | 0.32 | 0.12 | 0.43 | 0.15 | |
| 3D Angle (°) | | 7.03 | 2.16 | 14.92 | 9.37 | 9.47 | 7.01 | 10.41 | 1.27 | |
| XY-Angle (°) | | 7.08 | 2.19 | 11 | 6.45 | 7.07 | 4.58 | 8.96 | 1.9 | |

Note: Data are presented as med: median; min: minimum; max: maximum; IQR: interquartile range; Control: control group; AR: Augmented reality group. *P*: using Wilcoxon's signed-rank test. *: The differences between the control group and the AR group were assessed, and statistical significance was determined with a significance level of $P < 0.05$.

apical, from 0.67 to 0.11 mm; coronal, from 0.56 to 0.19 mm; Table 1). Additionally, the interquartile ranges (IQR) of the coronal and apical regions on the *y*-axis were decreasing from 0.29 to 0.10 mm and from 0.57 to 0.22 mm, respectively. Even though the results on the z-axis were not statistically significant between control and AR groups, the accuracy along z-axis in the coronal region was improved from 0.66 to 0.32 mm, with the IQR decreasing from 0.66 to 0.15 mm. For the senior clinician, the deviation of the 3D and *xy* plane angles decreased, and their IQRs decreased from 9.37° to 1.27° and from 6.45° to 1.90°, respectively.

## Comparison between the control and AR groups for the junior clinician

Most of the variables did not considerably differ between the control and AR groups (Table 2). However, in the AR group, the accuracy of the 3D angle considerably improved by 67% (from 12.93° to 4.46°). After the AR-aided system was used, the difference in the miniscrew apex considerably improved on the *y*-axis (from 0.88 to 0.25 mm). However, the accuracy of the coronal difference on the *y*-axis considerably deteriorated (from 0.36 to 1.34 mm).

After the AR-aided system was used, the *y*- and *z*-axis deviations and the 3D and *xy* plane angles decreased. The angle measurement deviations also decreased, with the IQRs of the 3D and *xy* plane angles decreasing from 3.22° to 0.59° and from 11.32° to 0.60°, respectively.

## Comparison between clinicians for the control group

When the traditional miniscrew placement method was used, a considerable difference was observed in the coronal

**Table 2** Comparison of the position and angle errors of miniscrew placement between the traditional method (control) and augmented reality (AR)-aided system when performed by a junior clinician.

| | | Control med | Control min | Control max | Control IQR | AR med | AR min | AR max | AR IQR | *P* |
|---|---|---|---|---|---|---|---|---|---|---|
| Apex (mm) | Total | 1.6 | 0.98 | 2.48 | 1.27 | 2.1 | 1.89 | 2.32 | 0.18 | |
| | dX | 0.74 | 0.49 | 0.97 | 0.22 | 0.33 | 0.04 | 0.87 | 0.58 | |
| | dY | 0.88 | 0.11 | 1.3 | 0.85 | 0.25 | 0.06 | 0.47 | 0.2 | * |
| | dZ | 0.27 | 0.09 | 2.37 | 2.17 | 1.94 | 1.86 | 2.24 | 0.26 | |
| Coronal (mm) | Total | 2.04 | 1.53 | 2.46 | 0.74 | 2.08 | 1.87 | 2.32 | 0.36 | |
| | dX | 0.62 | 0.05 | 0.87 | 0.5 | 0.25 | 0.05 | 0.8 | 0.57 | |
| | dY | 0.36 | 0.03 | 1.23 | 0.75 | 1.34 | 1 | 1.43 | 0.1 | * |
| | dZ | 1.58 | 1.39 | 2.43 | 0.86 | 1.51 | 1.38 | 1.88 | 0.33 | |
| 3D Angle (°) | | 12.28 | 7.38 | 19.34 | 3.22 | 4.46 | 3.27 | 4.67 | 0.59 | * |
| XY-Angle (°) | | 8.3 | 4.7 | 9.43 | 11.32 | 7.35 | 6.32 | 8.28 | 0.6 | |

Note: Data are presented as med: median; min: minimum; max: maximum; IQR: interquartile range; Control: control group; AR: Augmented reality group. *P*: using Wilcoxon's signed-rank test. *: The differences between the control group and the AR group were assessed, and statistical significance was determined with a significance level of $P < 0.05$.

**Table 3** Comparison of the position and angle errors of miniscrew placement between senior and junior clinicians when the traditional method (control) was used.

| | | Senior med | Senior min | Senior max | Senior IQR | Junior med | Junior min | Junior max | Junior IQR | *P* |
|---|---|---|---|---|---|---|---|---|---|---|
| Apex (mm) | Total | 1.35 | 0.43 | 1.8 | 0.81 | 1.6 | 0.98 | 2.48 | 1.27 | |
| | dX | 0.6 | 0.01 | 1.06 | 0.4 | 0.74 | 0.49 | 0.97 | 0.22 | |
| | dY | 0.67 | 0.01 | 0.96 | 0.29 | 0.88 | 0.11 | 1.3 | 0.85 | |
| | dZ | 0.82 | 0.28 | 1.32 | 0.76 | 0.27 | 0.09 | 2.37 | 2.17 | |
| Coronal (mm) | Total | 0.96 | 0.67 | 1.24 | 0.43 | 2.04 | 1.53 | 2.46 | 0.74 | * |
| | dX | 0.61 | 0.01 | 0.72 | 0.43 | 0.62 | 0.05 | 0.87 | 0.5 | |
| | dY | 0.56 | 0.06 | 0.96 | 0.57 | 0.36 | 0.03 | 1.23 | 0.75 | |
| | dZ | 0.66 | 0.02 | 0.8 | 0.66 | 1.58 | 1.39 | 2.43 | 0.86 | * |
| 3D Angle (°) | | 7.03 | 2.16 | 14.92 | 9.37 | 12.28 | 7.38 | 19.34 | 3.22 | |
| XY-Angle (°) | | 7.08 | 2.19 | 11 | 6.45 | 8.3 | 4.7 | 9.43 | 11.32 | |

Note: Data are presented as med: median; min: minimum; max: maximum; IQR: interquartile range. *P*: using Mann—Whitney U test. *: The differences between the senior group and the junior group were assessed, and statistical significance was determined with a significance level of $P < 0.05$.

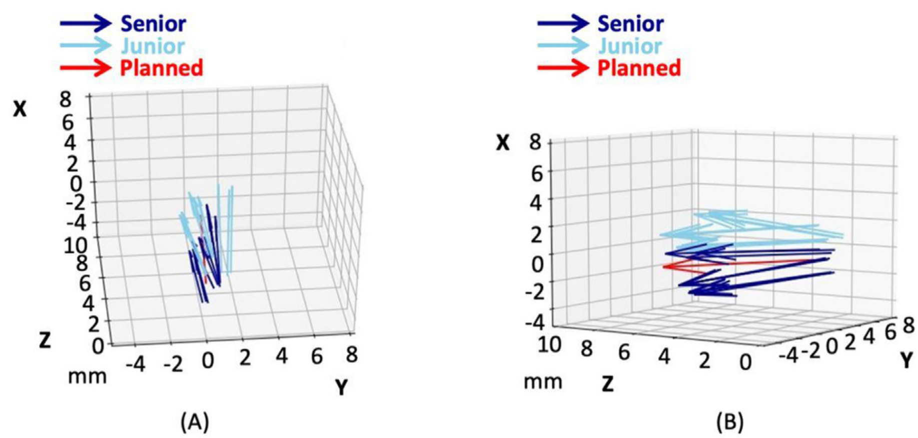


**Figure 5** 3D images from different perspectives of miniscrew positions in the control group. The arrow represents the apex of each miniscrew. Compared with the miniscrew positions of the senior clinician, the miniscrew positions of the junior clinician seem to be more divergent.

**Table 4** Comparison of the position and angle errors of miniscrew placement between senior and junior clinicians when the augmented reality (AR)-aided system was used.

| | | Senior med | Senior min | Senior max | Senior IQR | Junior med | Junior min | Junior max | Junior IQR | *P* |
|---|---|---|---|---|---|---|---|---|---|---|
| Apex (mm) | Total | 1.01 | 0.66 | 1.55 | 0.47 | 2.1 | 1.89 | 2.32 | 0.18 | * |
| | dX | 0.51 | 0.15 | 0.7 | 0.37 | 0.33 | 0.04 | 0.87 | 0.58 | |
| | dY | 0.11 | 0 | 0.36 | 0.1 | 0.25 | 0.06 | 0.47 | 0.2 | * |
| | dZ | 0.71 | 0.44 | 1.51 | 0.76 | 1.94 | 1.86 | 2.24 | 0.26 | * |
| Coronal (mm) | Total | 0.68 | 0.47 | 1.17 | 0.49 | 2.08 | 1.87 | 2.32 | 0.36 | * |
| | dX | 0.55 | 0.28 | 1.12 | 0.58 | 0.25 | 0.05 | 0.8 | 0.57 | |
| | dY | 0.19 | 0.04 | 0.42 | 0.22 | 1.34 | 1 | 1.43 | 0.1 | * |
| | dZ | 0.32 | 0.12 | 0.43 | 0.15 | 1.51 | 1.38 | 1.88 | 0.33 | * |
| 3D Angle (°) | | 9.47 | 7.01 | 10.41 | 1.27 | 4.46 | 3.27 | 4.67 | 0.59 | * |
| XY-Angle (°) | | 7.07 | 4.58 | 8.96 | 1.9 | 7.35 | 6.32 | 8.28 | 0.6 | |

Note: Data are presented as med: median; min: minimum; max: maximum; IQR: interquartile range. *P*: using Mann—Whitney U test. *: The differences between the senior group and the junior group were assessed, and statistical significance was determined with a significance level of $P < 0.05$.

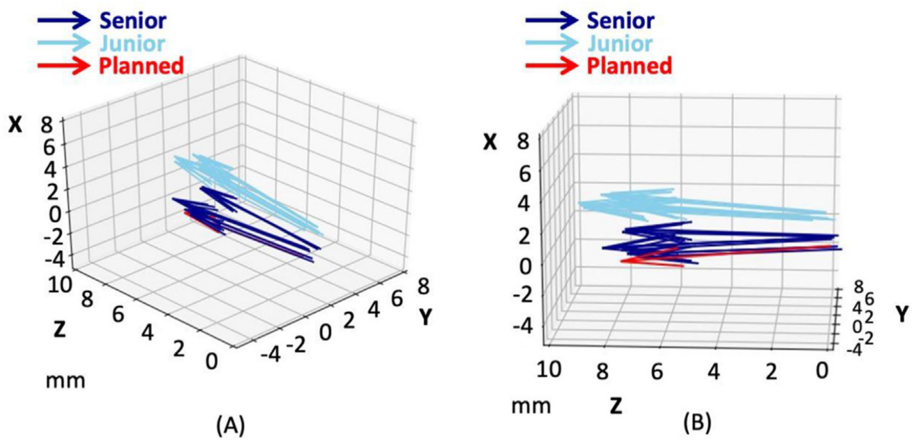


**Figure 6** 3D images from different perspectives of miniscrew positions in the augmented reality (AR)-aided system group. The arrow represents the apex of each miniscrew. With the help of the augmented reality (AR)-aided system, the positions of the miniscrews were centralized for both the senior and junior clinicians, and the spatial angle was parallel to the planned direction of miniscrew placement.

position between the two clinicians (0.96 and 2.04 mm for the senior and junior clinicians, respectively; Table 3). Subdivision of the axial directions revealed a substantial difference along the *z*-axis (0.66 and 1.58 mm for the senior and junior clinicians, respectively).

For the junior clinician, the *y*- and *z*-axes of the apex exhibited a high degree of dispersion with the overall error. The same result was also observed in the 3D positional image (Fig. 5). Compared with the senior clinician, the positions of the miniscrews appeared to be more divergent for the junior clinician. A spatial angle difference was also observed between the two clinicians, but the positions were all similarly dispersed in terms of direction.

### Comparison between clinicians for the augmented reality-aided system

When the AR-aided system was used, the differences in the miniscrew coronal and apical positions were 0.68 and 1.01 mm, respectively, for the senior clinician, and 2.08 and 2.10 mm, respectively, for the junior clinician (Table 4). A considerable difference was also observed in the errors of the apical and coronal positions. For the senior and junior clinicians, the 3D angle errors were 9.47° and 3.27°, respectively, and the *xy* angle errors were 7.07° and 7.35°, respectively. A considerable difference was observed in the 3D angle but not in the *xy* angle.

The data distribution for the apical error along the *y*-axis was more concentrated for the senior than for the junior clinician, with IQRs of 0.10 and 0.20 mm, respectively. However, the *z*-axis and overall errors were more concentrated for the junior than for the senior clinician. As depicted in the 3D positional image (Fig. 6), although the error of the coronal position was large for the junior clinician, the positions of the miniscrews were more centralized, and the spatial angle was more parallel to the planned direction of miniscrew placement (9.47° and 3.27°, respectively).

## Discussion

Miniscrews are often used in orthodontic treatment to prevent anchoring loss and improve treatment outcomes. To ensure miniscrew stability and prevent unnecessary complications, dental roots must be avoided during miniscrew placement. Before an orthodontic surgery is performed, planar X-ray films are typically used to determine the locations of the roots and other anatomical structures for the clinician's reference. However, X-ray films are only 2D images that provide limited information on which clinicians rely, in addition to their own experience, during miniscrew placement. Kuroda et al.[2] reported that 47.4% and 48.3% of the miniscrews placed using the traditional free-hand technique touched the tooth roots or damaged the surrounding tissues in the upper and lower jaws, respectively. Therefore, the success rate and precision of traditional free-hand miniscrew placement remain limited.

Because of the increasing popularity of CBCT, a large number of clinicians have relied on 3D images to devise detailed treatment plans for dental implant placement, thereby achieving favorable clinical outcomes.[1] In this study, the CBCT images generated by an AR-aided system were used to guide the placement of orthodontic miniscrews. The placement position and route were planned on the basis of patient CBCT images obtained in advance to assist senior clinicians in achieving improved positions and insertion angles for miniscrews, especially in the anterior teeth region, which is one of the most common orthodontic treatment areas. Hence, combining CBCT imaging with AR may facilitate miniscrew placement in extra-alveolar regions, such as in the palatal region.[20,21]

Because of the few errors observed along the *y*-axis (mesiodistal direction), the AR-aided system proposed in this study can help clinicians place miniscrews at the target location and avoid injury to the adjacent tooth roots compared with the traditional free-hand miniscrew placement technique. Bae et al.[11] reported that the insertion errors in the mesiodistal direction were 0.81 and 0.36 mm in the coronal and apical positions, respectively, when using the traditional method. In our AR group, the errors in the mesiodistal direction were 0.29 and 0.21 mm in the coronal and apical positions, respectively. This similarity between our results and those of Bae et al. suggests that the accuracy of our AR-aided system can be improved by using a guided plate. In an *in vitro* study,[22] a guiding plate was used to facilitate miniscrew placement on pig jawbones, and the results revealed measured differences of 1.01° and 1.16° in the vertical and horizontal angles, respectively.

In this study, the AR-aided system considerably reduced the miniscrew positioning error in the mesiodistal direction, indicating that this system can help junior clinicians avoid irreversible damage to adjacent roots, one of the most severe complications in orthodontic treatment, during miniscrew placement. However, for the senior clinician, no considerable difference in the miniscrew placement angle was observed between the traditional method and the AR-aided system.

When the AR-aided system was used by the junior clinician, the coronal position error increased by 272.22% (from 0.36 to 1.34 mm) on the *y*-axis (mesiodistal direction). This may have been caused by two factors. Firstly, the coronal position error in the control group was larger for the junior clinician than for the senior clinician, indicating that, because of the lack of experience, the junior clinician may have been unable to identify the appropriate insertion position for the miniscrew. Secondly, the display device of the AR-aided system sometimes partially obscures the entry point of the miniscrew, which makes determining the entry point more difficult for inexperienced junior clinicians, thus resulting in large errors. However, for senior clinicians with extensive clinical experience in clinical procedures, AR-aided systems can reduce such errors compared with the traditional free-hand miniscrew placement technique.

This study has some limitations. Because the wearable AR devices used were not equipped with a gyroscope or a telephoto lens appropriate for the dental field (commercial AR devices have a wide-angle lens but cannot be used at smaller scales during orthodontic surgery), they were unable to rapidly acquire images of reference points or allow real-time position correction in overlapping images. Therefore, this study was performed using a fixed camera and an *in vitro* model. In addition, simulating actual clinical operation conditions, such as patient head movements and limited vision due to the cheek and tongue, remains unfeasible. To adjust the entry point or angle of the miniscrews, clinicians should perform miniscrew placement from different perspectives. However, in this study, only one camera was used to obtain images from a single perspective. Therefore, in the future, multiple cameras should be used to provide additional perspectives for miniscrew placement. As an alternative, wearable AR devices with high-quality hardware, including a gyroscope and a telephoto lens, should be developed for use in dentistry. Such an innovation would increase the effectiveness of AR-aided systems in orthodontic treatment.

The conclusions of this study are as follows: Firstly, as compared with the traditional method of free-hand miniscrew placement, the AR-aided system developed in this study can improve the accuracy of miniscrew placement regardless of the clinician's level of experience. Secondly, the miniscrew placement exhibited reduced positional error for the less experienced clinician when employing the AR-assisted system compared to the more experienced clinician.

## Declaration of competing interest

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

## Acknowledgments

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