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A new method to evaluate the positional stability of a self-drilling miniscrew

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Structured Abstract

Objectives – To evaluate the positional stability of miniscrews during orthodontic treatment change in cone-beam computed tomography (CBCT).
Setting and Sample Population – Twenty adult volunteers were enrolled.
Methods – In all participants, at least two maxillary first premolars were extracted because of protrusion. Each volunteer received six miniscrews in the maxilla, including two loaded miniscrews to retract anterior teeth and four unloaded miniscrews. CBCT scans were obtained at the beginning of space closure (T1) and approximately 11.8 months later (T2). Three-dimensional miniscrew models were constructed at T1 and T2, and the central axes were calculated using a principal component analysis (PCA) technique. Finally, we measured and compared the angle change of all the miniscrews from T1 to T2.
Results – The angle change values of the unloaded and loaded miniscrews were $1.64 \pm 1.25°$ and $1.67 \pm 1.15°$, respectively. No significant differences in the angle change were observed.
Conclusion – Cone-beam computed tomography images revealed both the unloaded and loaded miniscrews to be positionally stable during en-masse retraction in this study.

Key words: cone-beam computed tomography; miniscrew; orthodontic treatment; stability

Introduction

Orthodontic miniscrews are commonly used to achieve absolute anchorage during tooth movement. Due to their numerous advantages, including their small size, minimal anatomical limitations, minor surgery, immediate loading, and lower costs, they have been widely used in various clinical situations such as anterior teeth retraction (1) or intrusion (2, 3), molar distalization (4) or intrusion (5), and occlusal plane canting correction (6). However, it is still not clear whether miniscrews are sufficiently stable to serve as stable markers for the 3D superimposition of cone-beam computed tomography (CBCT) images.

About half a century ago, Björk (7, 8) used metallic implants to study craniofacial growth and development. He established a structural superimposition method for the evaluation of jaw growth and teeth displacement on a lateral head film. However, his knowledge of jaw growth and development was two-dimensional and did not tell the whole story of craniofacial changes due to the limitation of measuring objects. In the late 1990s, CBCT was first introduced for use in imaging of the oral and maxillofacial region (9). Similar to spiral CT, CBCT enables the three-dimensional (3D) visualization of the craniofacial skeleton and teeth, which facilitate an accurate 3D study of jaw growth. A relatively lower radiation dose and higher space resolution make CBCT a common diagnostic tool in orthodontics. As CBCT can record 3D information of the craniofacial skeleton, it would be possible to gain insights into 3D during treatment changes of the teeth and jaw if the anchorage miniscrews could be used in lieu of Björk's metallic implants. Although Björk implants are considered stable, no one actually knows how miniscrews behave under orthodontic forces.

In 2004, Liou was the first to investigate the positional stability of miniscrews under orthodontic force and concluded that while miniscrews provide stable anchorage, they do not remain completely stationary throughout orthodontic loading (10). Contrarily, Wehrbein investigated the positional stability of palatal miniscrews and reported the opposite findings (11). However, both of these studies were based on two-dimensional cephalometric measurements.

EI-Beialy et al. (12). and Liu et al. (13). studied the behavior of miniscrews in three dimensions. The entire jaw was used as the reference registration structure to evaluate the stability of miniscrews. They found that miniscrews moved under orthodontic loading. Three-dimensional evaluation of the behavior of the miniscrew is more comprehensive than cephalometric measurements, but the uncertain stability of the registration structure and the artifact caused by metallic implant has reduced its superiority.

Recently, Kim et al. (14). studied the positional stability of surface-treated mini-implants (C-implants) using a 3D superimposition technique that allowed for subvoxel accuracy and highly robust registration. The maxillary sinus and palate were designated as the registration areas, and the study findings indicated that C-implants could provide stationary anchorage during orthodontic tooth movement. Nevertheless, the reliability of the registration area and artifacts of the implant continued to pose problems in the above study.

In this study, we used unloaded miniscrews as reference markers to evaluate the positional stability of anchorage miniscrews based on 3D CBCT images. A new method, which is not as severely influenced by the presence of artifacts, was adopted in this study.

Materials and methods

The subjects, miniscrew implantation procedure, and orthodontic treatment have been previously described (15). Briefly, 20 patients (14 women and six men) ranging from 21 to 41 years of age (mean age, 24 years) were included in this study. Criteria for inclusion were as follows: 1) the patient had a Class I or Class II malocclusion and protrusive upper incisors with treatment that included required maximum anchorage control; 2) the patient had a convex facial profile; 3) there were no missing permanent teeth in the upper arch; 4) the patient was over 18 years of age; and 5) the patient was in good health with no chronic disease or disability. The sample consisted of 13 angle Class I and 7 Class II malocclusions, including 11 skeletal Class I and 9 skeletal Class II malocclusions. The average overbite (OB) was 2.9 mm with one open bite case (OB: −5 mm), and the average over jet was 4.1 mm.

To reduce protrusion, the bilateral maxillary first premolars were extracted in all patients. Six self-drilling miniscrews (diameter, 1.6 mm and length, 11 mm; Ci Bei Corporation, Zhejiang, China) were placed in the maxilla of each participant. Two miniscrews inserted into the buccal inter-radicular space between the maxillary second premolar and first molar on both sides were used for en-masse retraction of anterior teeth, while four additional miniscrews placed in other inter-radicular spaces were not loaded. Unloaded miniscrews were primarily inserted between the lateral incisor and canine in the anterior region and between the first and second molars in the posterior region. In cases of insufficient amounts of bone in the original designed sites, they were inserted into an adjacent buccal area or corresponding palatal area. All the participants signed informed consent forms, and the research protocol was approved by the Ethics Committee of Peking University Biomedical Sciences.

All patients were bonded using a 0.022-inch straight wire appliance (Xin Ya Corporation, Zhejiang, China). En-masse anterior teeth retraction was completed using a stainless steel wire (0.019 in × 0.025 in) and a power chain with a force level between 1.5 and 2.5 N. Retraction of the anterior teeth against the miniscrews was stopped when the patient was satisfied with the profile or because of the molar relationship. The average duration of anterior teeth retraction was 11.8 months.

CBCT data acquisition

Scans were obtained with a CBCT machine (DCT pro; Vatech & EWOO Group, Seoul, South Korea) immediately after placement of the miniscrews (T1) and approximately 11.8 months later when the retraction of the anterior teeth was stopped (T2). According to the manufacturer's instructions, the patients were positioned in centric occlusion with lips closed and asked to remain still during the scanning procedure. All the scans were completed using the following protocol: field of view, 200 × 190 mm^2; 90 Kvp; 144 mA; scan time, 24 s; and voxel size, 0.3 mm^3.

The image quality of the metallic miniscrews used in this study considerably affected the result of measurement. It is believed that if metal is present in the field of view (FOV), X-ray imaging techniques are prone to producing artifacts. Unwanted movement of the patient's head also negatively influenced the scan quality. Four patients were excluded because of the severe image blur caused by metallic implants and/or patient motion.

Creation of a 3D model of the miniscrews

The following computer procedure was adopted for each patient. The patient's CT data were saved in digital imaging and communication in medicine (DICOM) format and managed by an interactive medical image control system (MIMICS 10.0, Materialise, Leuven, Belgium; Fig. 1). The metallic miniscrews were segmented from the maxilla on the basis of the image density threshold (3060-3072HU). If necessary, artifacts caused by the miniscrews were manually removed according to the standard shape of the miniscrew. 3D objects of the miniscrews were created in form of masks. The 3D models of each miniscrew were measured at both T1 and T2 (Fig. 2).

Angle change of the unloaded miniscrews

The stereolithography triangulated file of the four unloaded miniscrews was exported from Mimics software, and the first principal direction of each miniscrew was calculated using the principal component analysis (PCA) technique (16). In this study, the first principal component is the central axes of the miniscrew. We first

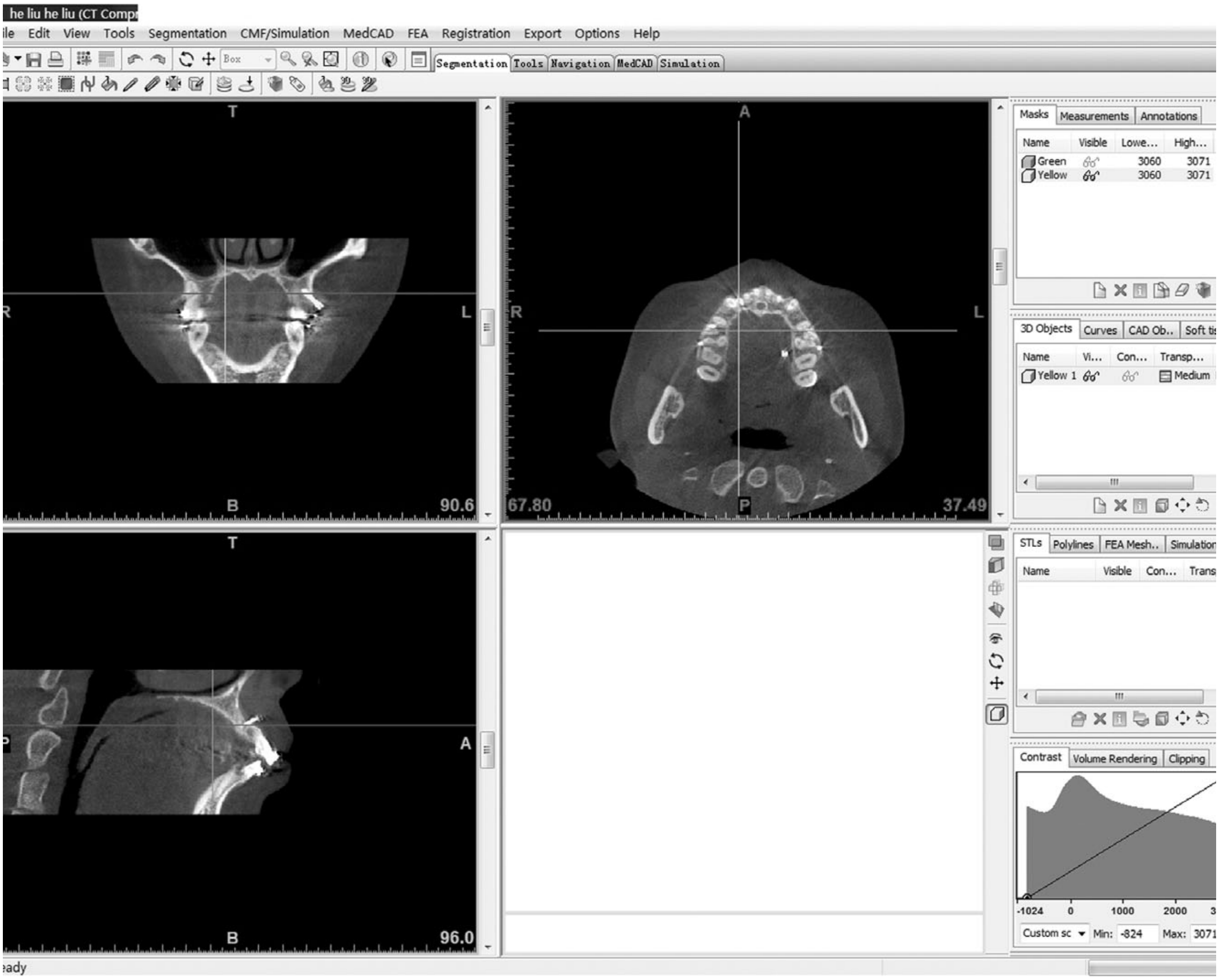

Fig. 1. CBCT slices imported to Mimics software.

performed PCA to obtain the first principal component of all miniscrews. The corresponding projection directions represent the central axes of the miniscrew (Fig. 3).

The angle between the unloaded miniscrews was measured from a, b, c to d (Fig. 4). If the angle change between the same two unloaded miniscrews from T1 to T2 was greater than (but not equal to) 5.0°, at least one of the two miniscrews were considered to have displaced in this time period, and they were marked as 'suspect miniscrews'. If the loaded miniscrews are displaced in the simplest tipping pattern possible, as reported by EI-Beialy et al. (12), the miniscrew heads are displaced on average in the direction of the force application (mean, 1.08 mm) while the tails move in the opposite direction (mean, 0.83 mm). The miniscrews used in this study were 1.6 mm in diameter and 11 mm in length, and a 5° change was approximately equal to 0.5 mm displacement of the miniscrew head. In our previous study (15), two unloaded miniscrews that exhibited a distance change of <0.5 mm were considered positionally stabile. Next, the remaining unloaded miniscrews were used to determine which of the suspect miniscrews had moved.

Angle change of the loaded miniscrews

The 3D models of the two loaded miniscrews at T1 and T2 were registered using the iterative closest point (17) method, in which initial rotation and translation matrices were estimated using stationary unloaded miniscrews. Furthermore,

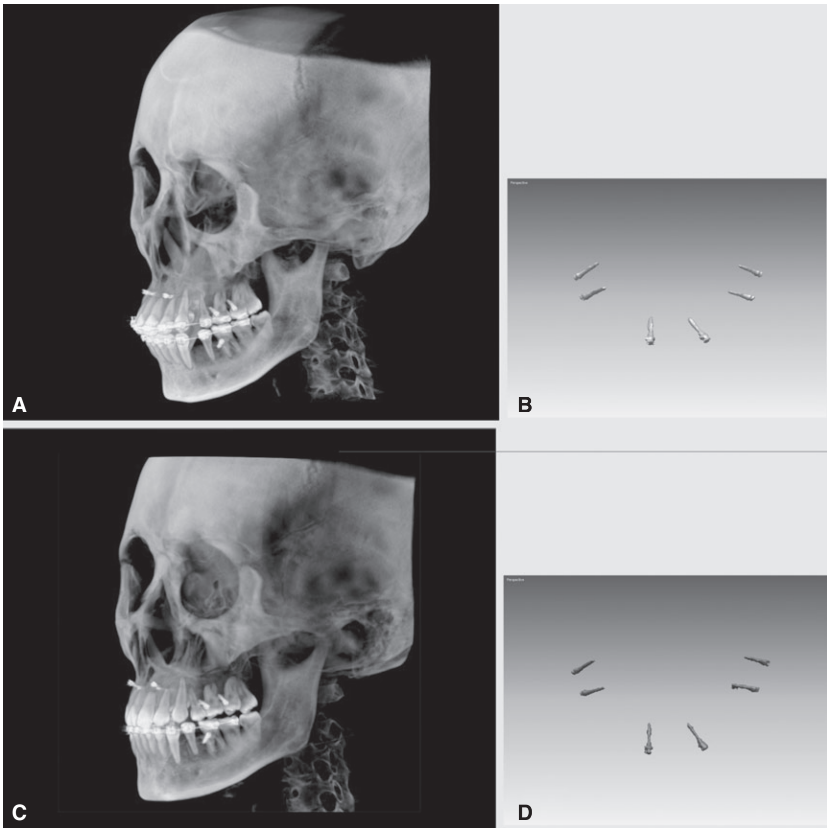

Fig. 2. CBCT image of a participant at T1 (A); 3D models of miniscrews constructed from the CBCT images obtained at T1 (B); CBCT image of the same participant at T2 (C); 3D models of the miniscrews created from CBCT images obtained at T2 (D).

Fig. 3. The central axis of the miniscrew (left) and the first principal component of the same miniscrew (right).

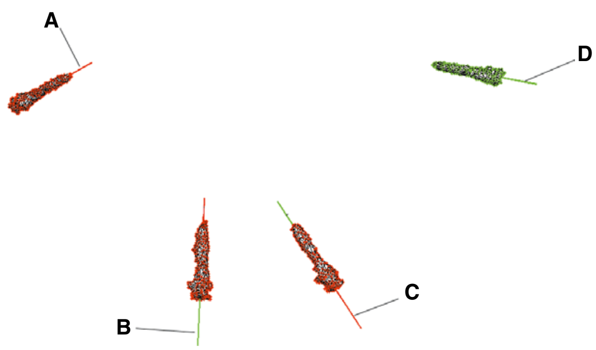

Fig. 4. Lines a, b, c, and d represent the first principal components of four unloaded miniscrews. The angles formed by the two adjacent lines (depicted in red and green) were calculated.

the angle changes in the loaded miniscrews from T1 to T2 were measured.

Displacement of miniscrews

Dental impressions were obtained using polysiloxane impression material (Affinis, Coltène Whaledent AG, Altstätten, Switzerland), and

Table 1. **Comparison of angle change between the reference and loaded miniscrews (T1–T2)**

Miniscrew type	N	Mean (degree)	SD	*t*	*p*-Value
Unloaded	44	1.64	1.25	0.085	0.933
Loaded	35	1.67	1.15		

Table 2. **Comparison of distance change between the unloaded and loaded miniscrews (T1–T2)**

Miniscrew type	N	Mean (mm)	SD	*t*	*p*-Value
Unloaded	55	0.22	0.09	−1.267	0.209
Loaded	38	0.25	0.14		

dental models were created and scanned using a 3D spot laser scanner (LPX-1200; Roland DG, Hamamatsu, Japan). Firstly, the distance between unloaded miniscrews was measured on maxillary digital dental models (both T1 and T2). The positional stability of unloaded miniscrews was evaluated by comparing the change in distance between two adjacent miniscrews. Then, maxillary digital T1 and T2 models were registered, and the positional stability levels of anchoring miniscrews were evaluated. This method was described in our previous study (15).

Statistical analysis

Each measurement was repeated thrice by three postgraduates, and the results were averaged. Independent samples *t*-test ($p < 0.01$) was performed on the angle changes and displacement of the loaded and unloaded miniscrews. Intraclass correlation coefficient (ICC) was calculated to test the interobserver reproducibility of measurement.

Results

A total of 120 miniscrews were placed in the maxilla of the 20 patients in this study. Five of the 80 reference miniscrews and two of the 40 loaded miniscrews failed during the 11.8-month retraction period. The remaining miniscrews remain clinically stable. One unloaded miniscrew whose angle change was bigger than 5° and was excluded. Interobserver measurement reproducibility, which is shown by the ICC, was 0.99 (angle change) and 0.97 (displacement).

The values of angle change of the unloaded and loaded miniscrews were $1.64 \pm 1.25°$ and $1.67 \pm 1.15°$, respectively. No significant differences were observed in the angle change between the two groups (Table 1).

The distance change of the miniscrew head was measured on digital dental casts. The mean values of displacement of the unloaded and loaded miniscrews were 0.22 ± 0.09 and 0.25 ± 0.14 mm, respectively. However, there was no significant difference in the mean displacement between the two groups (Table 2).

Discussion

Miniscrews are biologically compatible temporary anchorage devices (TADs) used in orthodontics to provide absolute anchorage and facilitate the movement of teeth but certain risks, such as root damage, can occur (18). Even if the TADs were placed in the 'safe zones' suggested by Poggio (19), the possibility of root injury still exists when the tooth or TAD moves under orthodontic load, as reported previously (10, 12, 13). When this occurs, it is not clear whether the tooth moves to collide with the TAD, *vice versa*, or whether both the tooth and TAD move toward each other. Studies on this subject have employed various methods (including 2D and 3D) and tested various TADs [including diameter-reduced TADs and length-reduced TADs, machine surfaced and surface-treated TADs, self-drilling and self-taping TADs (20)], all yielding different results.

Both Liou et al. (10). and Wehrbein et al. (11). carried out 2D cephalometric measurement-based studies. However, superimposition of cephalometric radiographs is subject to two types of error. The first originates from the single head film used, causing difficulty in identification of landmarks, overlapping of anatomical structures, head posture changes, and magnification (21, 22).

The second error arises from the selection of a stable reference structure for superimposing serial head films (23). Furthermore, a cephalometric radiograph is only a 2D projection of a 3D structure; therefore, it cannot wholly illustrate the behavior of the TAD.

EI-Beialy et al. (12). first studied the behavior of miniscrews in a three-dimensional plane using spiral CT. The maxilla and mandible were three-dimensionally reconstructed and used as a stable registration structure to evaluate the stability of miniscrews. This study reported that miniscrews were displaced in the direction of orthodontic loading, and that the displacement occurred in the movement of the head and tail, and extrusion of the miniscrews.

There are more unsolved questions with regard to 3D superimposition. First, stable volume structures remain unknown. Bjork defined stable structures as 2D projections of a 3D structure; however, this does not indicate that the structures themselves are stable. Second, the question of how to deal with metallic artifacts in CBCT images remains to be answered. Third, it is not yet known how a miniscrew in a 3D image can be considered stable when it is not projected on the 2D cephalogram.

In this study, three measures were taken to improve the reliability:

First, unloaded miniscrews were designed for use as reference structures. According to a study by Julius, migration, and occasionally dislodgment, of an unloaded implant was found to cause significant errors in implant superimposition (24). We questioned whether unloaded miniscrews could also migrate during orthodontic treatment and therefore not qualify as a reference structure. However, the angle change of the two unloaded miniscrews from T1 to T2 was $1.64 \pm 1.25°$. We attributed this minor angle change to the artifacts caused by partial volume averaging, the metallic miniscrew, and motion blur. The spatial resolution (voxel size, 0.3 mm^3) of the CBCT machine used in this study was not perfect; this may also be a potential source of error.

Second, PCA, which is robust to noise, was adopted to calculate the directions of the miniscrews. PCA is widely used in applications such as dimensionality reduction, lossy data compression, feature extraction, and data visualization. This technique determines the intrinsic dimensionality of data, which is usually lower than the observed dimensionality. In this procedure, a set of orthogonal directions is determined, which maximize the variance of the projected data. The linear space spanned by the orthogonal directions is called the principal subspace, and the projected data are called the principal components (16). These principal components are ranked by their variances, which are proportional to the amount of information they maintain. PCA is robust to noise because of the consideration of whole data, and the first several principal components usually have an intuitive meaning. For example, the direction of the first principal component of a pen is its central axis. The only manual operation during the whole measurement was the manual removal of artifacts according to the standard shape of the miniscrew, where necessary. No landmark was required for identification on the 3D image.

Finally, the digital dental model was combined with CBCT data. It is known that the absence of angle change of miniscrews alone cannot prove their positional stability in case of bodily movement. Therefore, we measured the distance changes between the unloaded and loaded miniscrews on digital dental casts, as reported in our previous study (15) and found that the miniscrew heads were stationary. By combining the results of angle change from the CBCT data and distance change from the digital dental casts, it could be said that the miniscrews used in this study remained positionally stable throughout the orthodontic treatment.

Finally, although the 3D method used in the present study revealed that the miniscrews were stable, it is not clear whether other types of TADs with different lengths, diameters, or surface treatments will yield the same results. We encourage TAD users to investigate the stability of different miniscrews with different loadings, and in subjects of different ages, to obtain greater depth of knowledge of 3D craniofacial biology.

Conclusion

In this study, we established a new method, to evaluate the positional stability of self-drilling miniscrews, which is not as severely influenced by the presence of metallic artifacts.

Both the unloaded and loaded miniscrews used in this study showed positional stability during en-masse retraction in adults. Therefore, at least this kind of miniscrew could be used as a stable marker for the 3D superimposition of CBCT images to assess changes during orthodontic treatment.

Clinical relevance

Although miniscrews are considered to provide absolute anchorage during orthodontic treatment, it remains unclear whether they are as stable as Bjork implants when loaded with orthodontic force. In this study, we aimed to evaluate whether miniscrews could serve to replace Björk implants during orthodontic treatment change in cone-beam computed tomography (CBCT), which will help us to find a rational way to superimpose the CBCT images of different time point.

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