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Research article

Accuracy of implant height and width measurement with triaxial rotation method based on cone-beam CT

Ziyang Hu [a,b,1], Zhengding Yuan [a,1], Dantong Cao [a], Rong Tang [a], Shu Liu [a], Shanhui Wen [a], Antian Gao [a], Zitong Lin [a,*]

[a] *Department of Dentomaxillofacial Radiology, Nanjing Stomatological Hospital, Affiliated Hospital of Medical School, Institute of Stomatology, Nanjing University, Nanjing, China*
[b] *Department of Stomatology, Shenzhen Longhua District Central Hospital, Shenzhen, Guangdong Province, China*

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ABSTRACT

Objective: To investigate the accuracy of implant height and width measurement in the mandibular and maxillary first molar region based on cone-beam CT (CBCT) data, and to establish an accurate method for bone measurement in the implant region.
Materials and methods: CBCT images of 122 patients with implant in mandibular or maxillary first molar region were retrospectively collected. Two methods were used to measure sagittal height (SH), coronal height (CH), sagittal width (SW), and coronal width (CW) of implants. Method 1 (general method): the images were analyzed using the built-in software NNT 9.0 software. SHl, CHl, SWl, and CWl were measured on the reconstructed sagittal and coronal based on the radiologist's own experience. Method 2 (triaxial rotation method): the raw data were demonstrated in Expert mode of NNT 9.0 software, in which the coronal axis and sagittal axis were rotated paralleling to the long axis of the implant for reconstruction, and then SH2, CH2, SW2, and CW2 were measured on the reconstructed sagittal and coronal images. The results of two methods were compared with the actual implant size (H0, W0). Paired T-test was performed for statistical analysis. Dahlberg formula was used to check the measurement error.
Results: For method 1, there was no significant differences between SHl and H0 ($P > 0.05$), but significant differences between CHl and H0, SWl and W0, and CWl and W0 ($P < 0.05$). For method 2, there were no significant differences between all measurements and actual size ($P > 0.05$). The random error range measured using Dahlberg formula was 0.157–1.171 mm for general method and 0.017–0.05 mm for triaxial rotation method.
Conclusion: The triaxial rotation method is accurate for implant height and width measurements on CBCT images and could be used in pre-operatively bone height and width measurement of potential implant sites.

1. Introduction

Dental implants have been widely used in clinic due to their high success rate. Accurate measurement of alveolar bone volume in

* Corresponding author. Department of Dentomaxillofacial Radiology, Nanjing Stomatological Hospital, Affiliated Hospital of Medical School, Institute of Stomatology, Nanjing University, Zhong Yang Road 30, Nanjing City, Jiangsu Province, 210008, China.
E-mail address: linzitong_710@163.com (Z. Lin).
[1] Co-first author.

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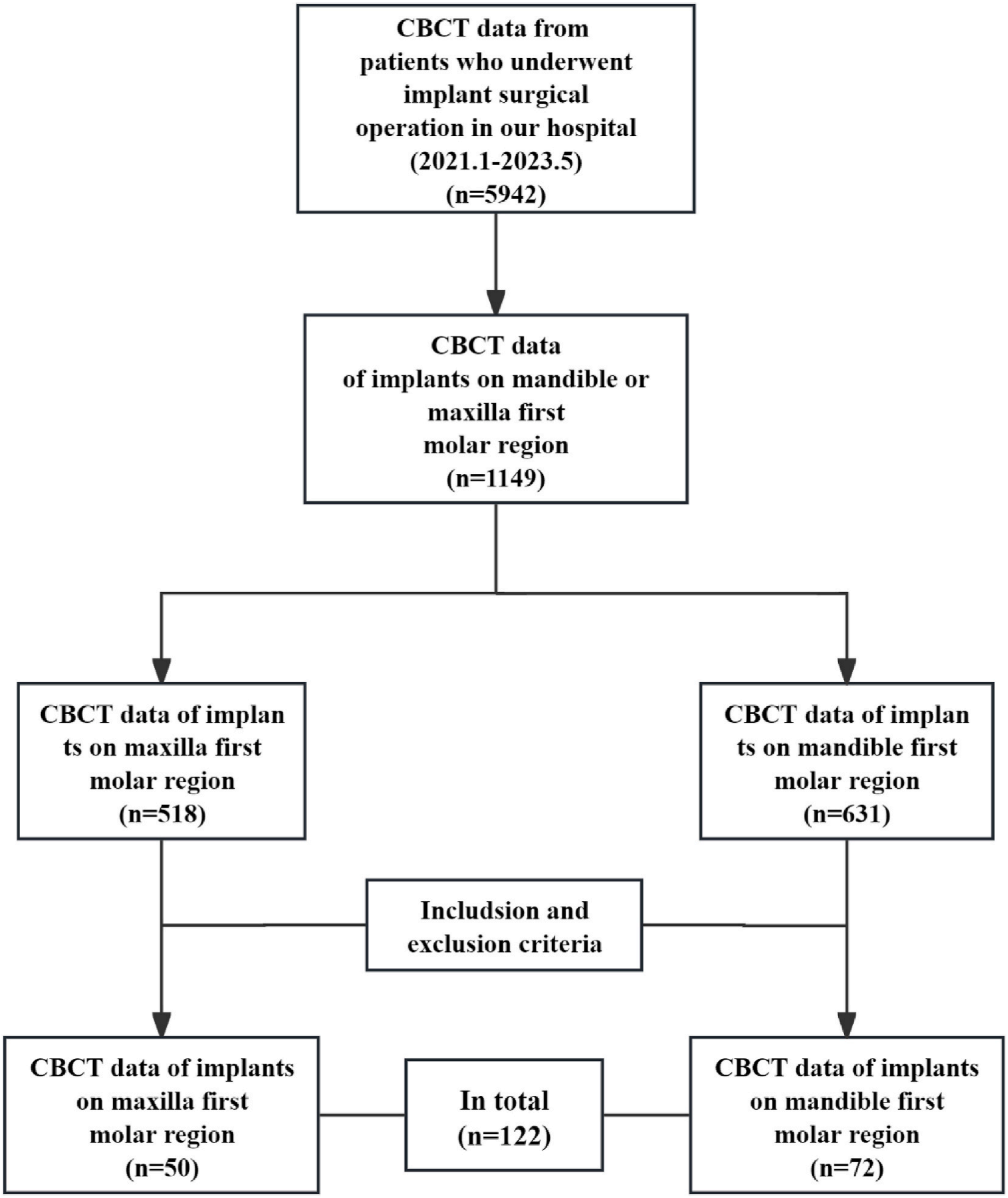

Fig. 1. Flow chart of CBCT data collection.

the edentulous area prior to surgery is crucial for surgical plans and the selection of implants [1]. Cone-beam computerized tomography (CBCT), as a radiographic technique, has significantly changed pre-operative treatment planning of implant sites [2–4]. Compared with periapical radiographs and digitalized panorama, CBCT allows depiction of the area of interest in three dimensions devoid of superimposition of anatomical structures, and provide more accurate and reliable measurements than traditional radiographs [5–9].

However, CBCT images are three-dimensional volume data, different reconstruction and measurement methods can lead to certain errors compared to reality [10–13]. In pre-operative bone measurements, the setting of three-dimensional reconstruction plane is crucial. A dimensional inaccuracy of 1–2 mm could be critical in the final selection of the implant size and type, as well as the surgical management of the implant site and placement. Therefore, establishing a precise and stable *in vivo* measurement method is important in clinical practice.

Currently, in clinic, the reconstruction and measurement of alveolar bone region of potential implant sites are usually based on the experience of the operator, and we found this could result in quite different and unstable measurement results. Therefore, in this study,

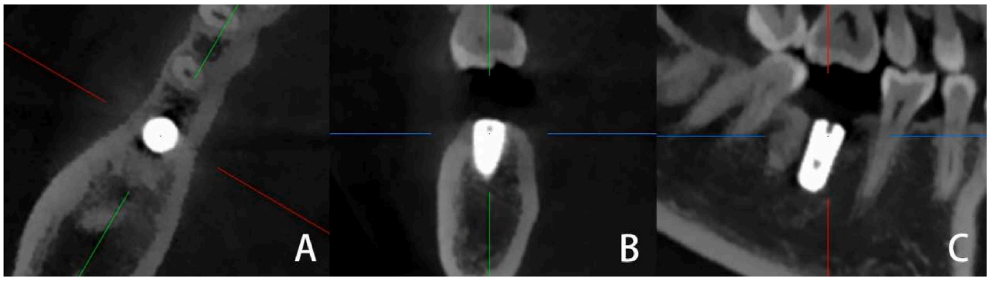

Fig. 2. Schematic diagram of general method. A was the axial image, B was the cortical image, C was the sagittal image, the red line was the cortical reconstruction plane, the green line was the sagittal reconstruction plane, the blue line was the axial reconstruction plane, all of them were perpendicular to each other, the red line and green line were perpendicular to the horizontal plane but not parallel to the implant long axis. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

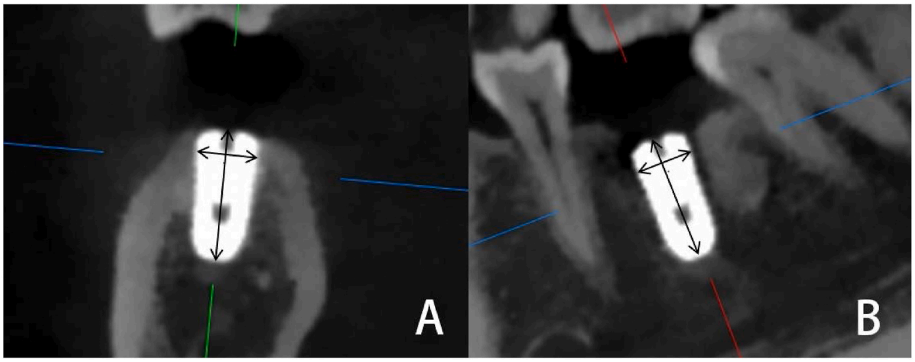

Fig. 3. Schematic diagram of measuring the height and width of the implant.the height is the length from the top midpoint to the bottom midpoint of the implant, and the width is measured 2 mm under the top of the implant.

a triaxial rotation method was established and used to measure the height and width of implant based on *in vivo* post-implantation CBCT data, and the accuracy and stability of this method was evaluated. We hope that our research could supply an accurate and stable method for both pre-operative and post-operative reconstruction and measurement of implant sites.

2. Materials and methods

2.1. Subjects

This study collected CBCT images of 122 patients who underwent implant surgery in mandibular or maxillary first molar region in our hospital (Fig. 1). The inclusion criteria were: (1) only one implant in mandibular or maxillary first molar region; (2) the implant with no obvious proximal, distal, buccal or lingual inclination; (3) the basal bone and alveolar process were nearly aligned; (4) the CBCT images were of good quality, without motion artifacts and foreign body artifacts. Exclusion criteria were: (1) periapical periodontitis or periodontitis of adjacent teeth; (2) obvious metal or motion artifacts on the CBCT images; (3) bone augmentation surgery during implant placement; (4) the presence of implant bases. The methodology of this study was formulated according to the guidelines stipulated by Strengthening the Reporting of Observational Studies in Epidemiology (STROBE).

The approval from the Ethics Committee of our University was obtained prior to performing this retrospective study (NJSH-2023NL-003).

2.2. CBCT data processing

2.2.1. CBCT examination

All CBCT images were taken using NewTom VGi scanner (QR SRL, Verona, Italy) with a voxel size of 0.30 mm, 110 kV, field of view of 15 × 12 cm and exposure time of 1.8 s.

2.2.2. Implant measurement

Sagittal Height (SH), Coronal Height (CH), Sagittal Width (SW), and Coronal Width (CW) of implants were measured.

For general method, a radiologist with more than 10 years of experience (radiologist A) used the inbuilt software NNT 9.0 (QR SRL, Verona, Italy). The sagittal and coronal images were reconstructed based on the experience of himself, and SH1, CH1, SW1, and CW1

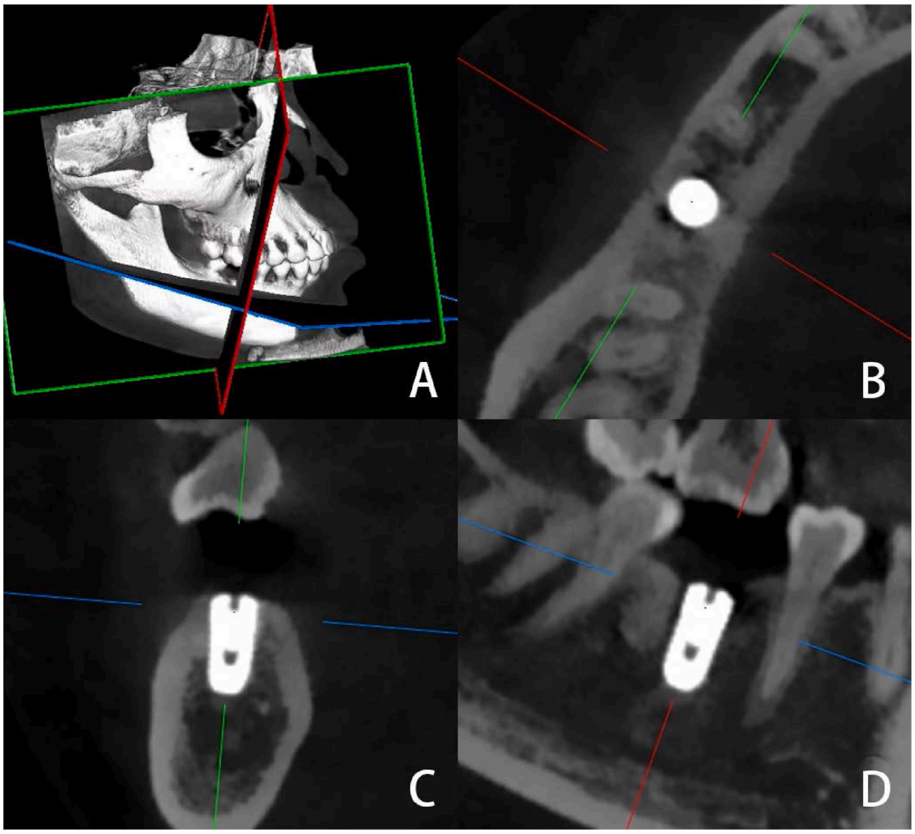

Fig. 4. Schematic diagram of triaxial rotation method: A was the three-dimensional volume rendering model showed the sagittal, cortical and axial reconstruction plane. B was the axial image, C was the cortical image, D was the sagittal image, the red line was the cortical reconstruction plane, the green line was the sagittal reconstruction plane, the blue line was the axial reconstruction plane, all of them were perpendicular to each other, the red line and green line were parallel to the long axis of implant. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

were measured on the reconstructed images [Fig. 2(A-C)]. The height is the length from the top midpoint to the bottom midpoint of the implant, and the width is the diameter measured 2 mm under the top of the implant [Fig. 3(A, B)].

For triaxial rotation method, radiologist A used the Expert mode of NNT 9.0. In this mode, the axial, sagittal and coronal reconstruction planes were perpendicular to each other and parallel to the implant's long axis and the alveolar bone's long axis [(Fig. 4(A-D)]. SH2, CH2, SW2, and CW2 were measured on the reconstructed sagittal and coronal images.

In order to evaluate the repeatability of these two methods, a radiologist with 2 years of experience (radiologist B) reconstructed and measured the same volume data with radiologist A. After four months, radiologist A reconstructed and re-measured all the volume data again. The intraclass correlation coefficients (ICCs) of radiologist A versus radiologist B and radiologist A in first time and second time were analyzed for the two methods.

To reduce the partial volume effects as much as possible, a calibration experiment was conducted. A 4.8*10 mm implant was scanned beside five volunteers who underwent CBCT examinations for implantation. The height and the width of the implant were measured using the triaxial rotation method at different window level to determine the optimal window level with the fewest distortions (radiologist C). Finally, the window level of the CBCT images was set as 13%–55 % for measurement of implant size. And for the CBCT volume data of the same patient, the measurements using the two methods (general and triaxial rotation method) were performed in complete congruent window level. Before measurements, unified training of reconstruction methods and measurement standard was performed.

The relevant model and argument of the implants was accessed in the Electronic Medical Record system of our hospital by radiologist C. The two radiologists (radiologist A and B) performed all the measurements blindly and they were unaware of the actual implant size at all throughout the research.

2.3. Statistical analysis

Eight sets of data obtained by the two methods were compared [14]with the actual size of implant (H0, W0), and paired t-tests were performed using SPSS 23.0 statistics software (SPSS Inc., Chicago, IL, USA). A significance level of $P < 0.05$ was used to determine the

Table 1
T-test between two measurement methods and actual size of implant in maxilla and mandible.

Pairs	Mean ± SD/mm	P value
SH1–H0 (MA)	0.25 ± 0.55	0.003
SW1–W0 (MA)	0.34 ± 0.49	0.000
CH1–H0 (MA)	0.27 ± 0.51	0.000
CW1–W0 (MA)	−0.11 ± 0.43	0.085
SH2–H0 (MA)	0.03 ± 0.13	0.065
SW2–W0 (MA)	−0.03 ± 0.16	0.136
CH2–H0 (MA)	0.10 ± 0.17	0.292
CW2–W0 (MA)	−0.01 ± 0.14	0.492
SH1–H0 (ME)	0.28 ± 0.79	0.603
SW1–W0 (ME)	−0.65 ± 0.53	0.000
CH1–H0 (ME)	−0.86 ± 1.29	0.000
CW1–W0 (ME)	−0.99 ± 0.69	0.000
SH2–H0 (ME)	−0.02 ± 0.17	0.402
SW2–W0 (ME)	−0.03 ± 0.16	0.241
CH2–H0 (ME)	−0.02 ± 0.16	0.332
CW2–W0 (ME)	−0.03 ± 0.14	0.068

SH: Sagittal Height, CH: Coronal Height, SW: Sagittal Width, CW: Coronal Width; 1: Measurement with general method; 2: Measurement with triaxial rotation method; 0: Actual size of implant; ME: Mandible; MA: Maxilla.

Table 2
T-test between two measurement methods and actual size of implant in maxilla and mandible together.

Pairs	Mean ± SD/mm	P value
SH1–H0	0.12 ± 0.71	0.068
SW1–W0	−0.52 ± 0.54	0.000
CH1–H0	−0.40 ± 1.18	0.000
CW1–W0	−0.63 ± 0.74	0.000
SH2–H0	0.02 ± 0.15	0.087
SW2–W0	−0.03 ± 0.16	0.073
CH2–H0	−0.02 ± 0.15	0.297
CW2–W0	−0.02 ± 0.14	0.065

SH: Sagittal Height, CH: Coronal Height, SW: Sagittal Width, CW: Coronal Width; 1: Measurement with general method; 2: Measurement with triaxial rotation method; 0: Actual size of implant.

presence of significant differences.

Dahlberg formula was used to check the measurement error (radiologist A and radiologist A after four month), and if it was less than 3 % of the total variance, the measurement error was considered acceptable.

$$S_D = \sqrt{\sum_{i=1}^{n} d_i^2 \Big/ 2n}$$

Dahlberg formula (d difference between repeated measurement values, n sample size).

3. Results

The statistical analysis of the measurements using the two methods compared with the actual implant size was shown in Table 1. For the general method in the mandibular first molar region, the difference between the sagittal height with the actual size of implant was not significant ($p > 0.05$), but the differences between the sagittal width, coronal height, and coronal width with the actual size of implants was significant ($p < 0.05$). For the general method in the maxillary first molar region, the differences between the cortical width with the actual width was not significant ($p > 0.05$), but the differences between the sagittal height, sagittal width and coronal height with the actual size of implants was significant ($p < 0.05$). For triaxial rotation method, the differences between the sagittal height, sagittal width, coronal height and coronal width with the actual size of implants were all not significant ($p > 0.05$) in both maxillary and mandibular first molar region.

The statistical analysis of the measurements using the two methods in maxilla and mandible together compared with the actual implant size was shown in Table 2. For the general method, the difference between the sagittal height and the actual size of implant was not significant ($p > 0.05$), but the differences between the sagittal width, coronal height, and coronal width with the actual size of implants was significant ($p < 0.05$). For the triaxial rotation method, the differences between the sagittal height, sagittal width, coronal

Table 3
Repeatability analysis of two measurement methods.

	A1 vs. A2	A1 vs. B
SH1	0.983	0.480
SW1	0.859	0.251
CH1	0.800	0.450
CW1	0.969	0.055
SH2	0.999	0.952
SW2	0.910	0.778
CH2	0.988	0.914
CW2	0.940	0.740

SH: Sagittal Height, CH: Coronal Height, SW: Sagittal Width, CW: Coronal Width; 1: Measurement with general method; 2: Measurement with triaxial rotation method; A1: Radiologist A in first time, A2: Radiologist A in second time, B: Radiologist B.

Table 4
Dahlberg error of two measurement methods in radiologist A.

	General method	Triaxial rotation method
SH	0.315	0.024
SW	0.157	0.017
CH	1.171	0.05
CW	0.411	0.019

SH: Sagittal Height, SW: Sagittal Width, CH: Coronal Height, CW: Coronal Width.

height and coronal width with the actual size of implants were all not significant ($p > 0.05$).

The ICCs of radiologist A versus radiologist B and radiologist A in first time and second time were showed in Table 3. The triaxial rotation method showed better stability than the general method, especially between radiologist A and B.

The random error range measured using Dahlberg formula was 0.017-0,05 mm for triaxial rotation method and 0.157–1.171 for general measurement method (Table 4). For triaxial rotation method, the random error range measured did not exceed 3 % of the total variance, indicating that the measurement error was acceptable. For general measurement method, the random error range measured exceeded 3 % of the total variance, indicating that the measurement error unacceptable.

4. Discussion

In this study, the implant size measured using two measurement methods were quite different. For the general measurement method, there was no significant difference between the sagittal height and the actual height in mandibular first molar region, and between the cortical width with the actual width in maxillary first molar region. However, there were significant differences between all the other measurements with the actual size in both mandibular and maxillary first molar regions. We considered it was because the reconstruction did not pass through the central axis of the implant using general method. Therefore, the measurements were underestimated or overestimated. Moreover, the statistical analysis of the measurements using general method in maxilla and mandible together showed the sagittal height and the actual size of implant was not significant, but the others were all significant different. It indicated that we should be cautious about the measurements using general method, especially the measurements in the cortical plane. This is consistent with the results of Saberi et al.'s study, which found that there was significant difference in the height of the maxillary and mandibular implant measured on the coronal section in different directions [15]. Sabban et al. measured the distance between the marks on the maxilla and mandible at different inclinations on the coronal section and found significant differences. It showed that changing the angle between the coronal section and the mandible would result in differences in the measurement values of the mandibular height [16]. Neves et al. used CBCT to measure maxilla and mandibular bone height. It showed that the measurement value of the coronal position perpendicular to the horizontal plane was significantly different from the measurement value of the coronal position parallel to the implant long axis [17]. This is consistent with the results of our study.

For the triaxial rotation method, sagittal and coronal reconstruction planes are parallel to the long axis of the implant, and the intersection of the two planes is at the center of the implant cross-section. It could ensure that the two planes pass through the center axis of the implant. Therefore, the height and width measured by the triaxial rotation method have no significant difference with the actual size of implants in both mandible and maxilla. Because this study used postoperative CBCT data to measure implant height and width, when applying this method in preoperative evaluation, we should fully consider the direction of the implant. Moreover, the direction of the implant's long axis should be consistent with the direction of occlusal force, so that the implant and the base are subjected to less stress and the bone is subjected to uniform stress. It is conducive to bone integration of the implant and later stability, and improves the success rate of the implant [18].

In implant simulation and pre-operatively bone height and width measurement, we should 1) place the implant in a direction with full considering the long axis of adjacent teeth, the morphology of basal bone and the direction of occlusal force [19]; 2) rotate the

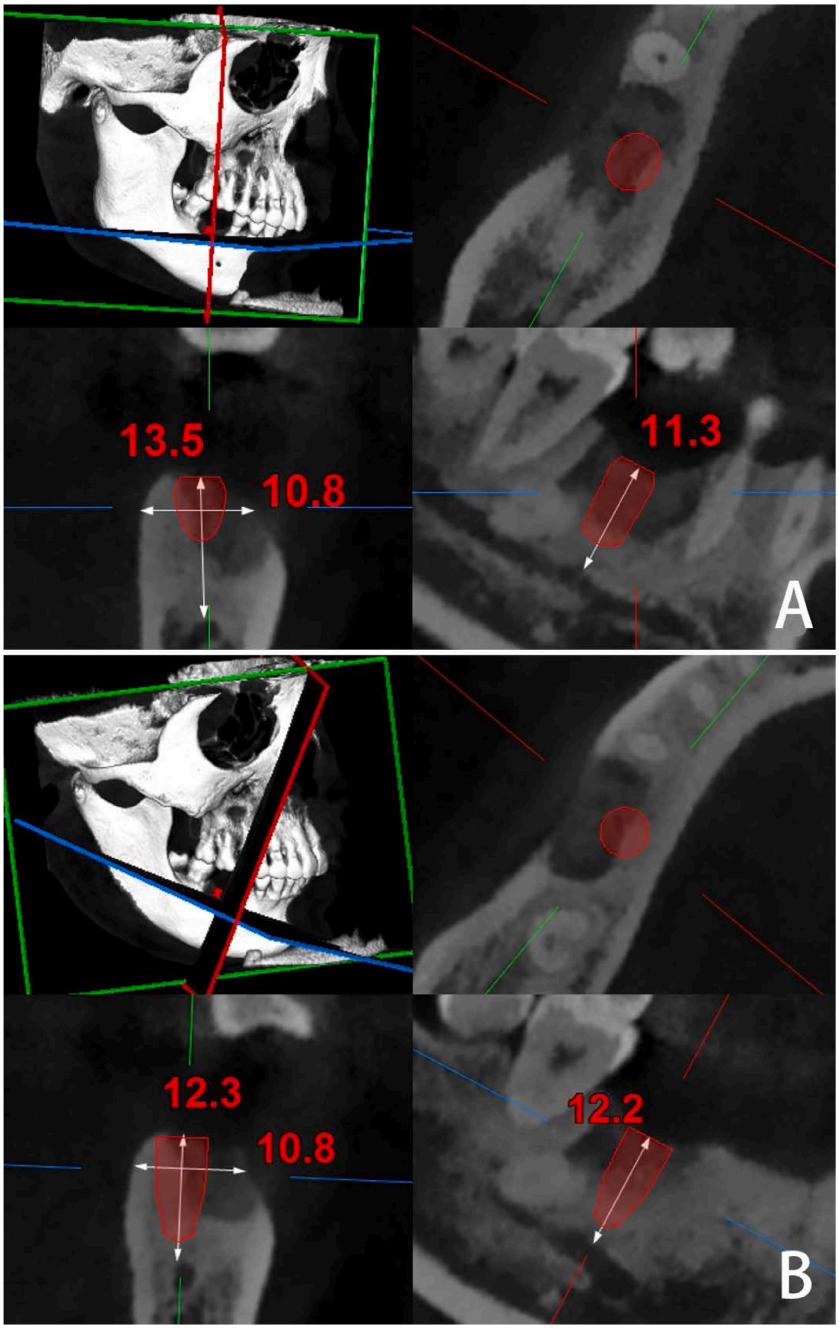

Fig. 5. An example of general method and triaxial rotation method in implant simulation and pre-operatively bone height and width measurement. A was general method; a simulated implant was placed in the implant region. The reconstructed cortical and sagittal plane were perpendicular to the horizontal plane but not parallel to the long axis of simulated implant, the bone height (from the alveolar bone process to the upper wall of mandibular never canal) measured was 13.5 mm in the cortical image and 11.3 mm in the sagittal image. And the doctor may select an implant with a height of 8.5 or 9 mm based on 11.3 mm bone height in the sagittal image. B was triaxial rotation method, the reconstructed cortical and sagittal planes were parallel to the long axis of simulated implant, and the bone height was 12.3 mm measured in the cortical image and 12.2 mm in the sagittal image. The doctor may select an implant with a height of 10 mm based on bone height in the cortical and sagittal image.

reconstructed cortical plane and sagittal plane parallel to the long axis of simulated implant [20,21]; 3) measure the bone height and width in the reconstructed sagittal and coronal images; 4) modified the simulated implant [(Fig. 5(A, B)].

In this study, the intergroup consistency using general method was less than 0.5 between evaluator A and evaluator B. The poor intergroup consistency indicates that there may be significant differences in measurement among different doctors in each measurement, which can lead to a large deviation in clinical practice [22,23]. This can affect the judgment of the distance of important anatomical tissues around the implant site, and ultimately affect the surgical planning. In contrast, the intergroup consistency in the triaxial rotation method group was equal to or greater than 0.75, indicating a smaller deviation in measurements among different doctors and a higher level of consistency. In addition, the measurement error calculated using Dahlberg formula shows random error range was acceptable for triaxial rotation method and unacceptable for general measurement method. It indicates the stability and accuracy of general method is lower than triaxial rotation method.

This study has several limitations: 1. only implants in mandibular and maxillary first molar region were collected, samples in mandibular and maxillary other regions need to be collected and evaluated in future. 2. The CBCT images used in this study are post-implant images, the implants height and width measurements and pre-operatively bone height and width measurement were not quite the same, although theoretically the triaxial rotation method is accurate in pre-operatively bone evaluation, it should be further verified in pre-implant planning. 3. The general method in this study is based on the experience of a radiologist, so the measurement values of errors should be objectively viewed. For different radiologist, the values could be variable.

5. Conclusion

The measurement of implant height and width using triaxial rotation method showed high accuracy and it could be used for accurate preoperative bone measurement in implantation in posterior or first molar regions.

6. Funding

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Data availability

Data will be made available on request.

CRediT authorship contribution statement

Dantong Cao: Resources, Investigation, Data curation. **Rong Tang:** Resources, Investigation, Data curation. **Shu Liu:** Investigation, Data curation. **Ziyang Hu:** Writing – original draft, Visualization, Software, Formal analysis, Data curation. **Zhengding Yuan:** Writing – original draft, Resources, Investigation, Formal analysis, Data curation. **Shanhui Wen:** Resources, Investigation, Data curation. **Antian Gao:** Resources, Investigation, Data curation. **Zitong Lin:** Validation, Supervision, Project administration, Funding acquisition, Yuehui Teng, Resources, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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