Reliability and validity of miniscrews as references in cone-beam computed tomography and intraoral scanner digital models: study on goat heads

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Research article

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Abstract

Background: Miniscrews have been used to superimpose craniofacial three-dimensional (3D) images or explore stable structures in jaws ,in spite of their artifact. Our purpose was to evaluate the reliability and validity of linear and angular measurements on a 3D model of miniscrews from cone-beam computed tomography (CBCT) at two voxel sizes and an intraoral scanner (IOS). Methods: Altogether, 64 miniscrews were placed in 12 jaws of goat. Jaws with miniscrews were scanned by CBCT machine at different voxels and IOS. Linear and angular measurements between miniscrews on CBCT at 0.12-mm and 0.3-mm voxels and the IOS were compared with actual measurements and with each other. Results: An intraclass correlation of 0.961–1.000 was obtained by each method. Significant overestimations of linear measurements of 0 .2 7 ± 0.24, 0.14 ± 0.22 and 0.15±0.26 mm, and non-significant differences of 0.11±1.97 °, 0.15±2.79° and 0.41±2.34°, were observed on CBCT at 0.12-mm and 0.3-mm voxels and the IOS, respectively. Equal magnification of linear measurements was on homolateral and contralateral sides using CBCT, whereas significantly greater magnification on the homolateral side than on the opposite was observed using the IOS. No significant difference was observed among three digital models on angular measurements. Conclusions: Miniscrews in CBCT and IOSs seem reliable and valid as reference measuring tooth movement. However, when miniscrews are involved in high precision measurement in CBCT or IOS image, the systematic error should be taken into consideration. Same voxels of CBCT images are recommended for miniscrew related measurements to reduce the type of error source.

Background

Traditional orthodontic records include plaster dental model, facial and intra-oral photo, panoramic radiograph and lateral headfilm , which could be used to monitor treatment progress and outcomes. Superimposing tracings of serial cephalograms has been used widely to determine the skeletal and dental changes that occur over time. The key to a good superimposition is the stable structure. These structures described in Melsen's research of cranial base growth [1], Bjork and Skieler's implant research [2,3], as well as Enlow's investigation of remodeling [4]are suggested by American Board of Orthodontics. The external reference -metallic implant, played a crucial role in locating the natural stable structures in maxilla and mandible and the superimposition of serial headfilms on metallic implants is considered to be the best technique.

Burgeoning developments in acquisition of medical images and 3D digital technologies have initiated revolutionary changes in orthodontics. Nowadays, CBCT , digital dental model and 3D facial photo have been introduced and used as new orthodontic records. The reliability and validity of these new records have been verified before they were used to make diagnosis and treatment plan. Similar to 2D cephalometric superimposition, orthodontists tried to register these 3D digital models to measure the changes over time in three dimensions. A great number of studies have focused on CBCTs and digital dental models superimpositon.

CBCT has been proven to be a valid 3D representation of the skull that is suitable for clinical and laboratorial use. Superimposition in nongrowing patients using CBCT models is not difficult because several stable craniofacial structures can be used for reference [5-7],but in growing patients, it is challenging because 3D stable structures in jaws haven't been identified. There are no other means to analyze the change in jaws of growing patients except by using external reference points [8]. Parton et al. [9]attempted to superimpose mandibular structures in growing rabbits with the aid of implants. Nguyen et al. [10] identified stable mandibular structures in three dimensions in growing patients with the aid of bone plates.

Recent decades have also witnessed remarkable advancements in digital dental model technologies, from stone dental model scanning to direct intraoral scanning . Digital technique makes superimposition of serial dental models possible. Palatal rugae have historically been used to perform 2D measurements on 3D dental models [11,12,13]. With the aid of miniscrews, Jang [14]and Chen [15] evaluate the stability of the palatal region and establish a 3D superimposition method for analyzing orthodontic tooth movement in maxillary dental models. However, the method to superimpose digital dental models in growing patients is still unknown to us, and again ,miniscrews could be served as external reference in the future study.

What calls for noteworthy attention is that studies showed that artifact caused by the metallic implant in CBCT will degrade image quality [16], which could bring errors into the procedure of implant superimpositon. Park [17] found that the borders of mental brackets were blurred in image created by image created by certain type of IOS, and literature does not support the use of IOSs for impression capture on multiple dental implants, aimed at the manufacture of extended implant-supported restorations as full arches[18].To date, no study has been done to evaluate the error when miniscrews are used as reference .

The aim of this study is to evaluate the reliability and validity of linear and angular measurements of miniscrews in CBCT at different voxel sizes and intraoral scanner . This was the first attempt to test systematic errors in miniscrew measurements of two digital methods in one study, and could serve as justification for further application of miniscrew superimposition on 3D models.

Methods

Four goat maxillae and four mandible were used in this *in vitro* study. The lower jaw was dissected further into two hemimandibles to make direct scanning possible. Maxillae and hemimandibles underwent miniscrew (11 mm × 1.6 mm; Ci Bei, Zhejiang, China) implantation by two experienced orthodontists. Two miniscrews on each side were on the buccal and lingual sides of each maxilla and hemimandible. At least one miniscrew on each hemimandible was penetrated out of the cortical bone from one side to another (Figure 1a, d). In all, 64 miniscrews were inserted.

CBCT and intraoral imaging

A NewTom GIANO system (Aperio, Sarasota, FL, USA) with a field of view of 11 cm × 11 cm × 5 cm and high resolution of 0.12-mm voxels was used to scan image all samples. Eight hemimandibles were rescanned re-imaged by 0.3-mm voxels. Invivo™ 6.0 (Anatomage, San Jose, California, USA) was used to generate 3D models by the preset threshold value of bone (Figure 1b, e). A 3Shape TRIOS IOS (3Shape Dental Systems, Copenhagen, Denmark) using a regular calibration procedure was applied for imaging *in vitro*. The imaging sequence is depicted in Figure 2. The 3D models were imported into RapidForm™ 2006 (INUS Technology, Seoul, Korea) for measurement.

Linear and angular measurement of miniscrews

Measurements were undertaken by a single operator thrice for each sample on three digital models and a digital caliper (Airaj, Tsingtao, China) on real miniscrews, and remeasured once by another operator to test inter-operator reliability. The surface center of the head and apex of each miniscrew were used as reference points. The point-to-point distance along a line was used as a linear measurement value (Figure 3a, b). A measurement was abandoned if either of the points could not be set stably using a caliper pointer. A visual measurement system, SmartScope® MVP (OGP, Singapore), was used to measure the angle between real miniscrews (Figure 3d). The angle had to consist of two ultimate points of one cortically penetrated miniscrew, and the third point was a surface center point of another miniscrew head or the apex of the miniscrew depending on which one was visually clear (Figure 3c). Half of the cap of the miniscrews was ground off using a high-speed handpiece to allow the setting of reference points.

Statistical analyses

Measurements taken by the digital caliper and Smartscope MVP were considered to be the real values. SPSS v25 (IBM, Armonk, NY, USA) was employed for statistical analyses. Intra- and inter-operator reliability was tested by intra-class correlation analysis (ICC). Then, the arithmetic mean value was calculated and used as the value of each measurement. All mean data were tested to follow the normal distribution, thus paired t-test was conducted to evaluate the validity of measurements of miniscrews in CBCT and intraoral imaging. The level of significance was set at $P<0.01$ for ICC and $P<0.05$ for paired t-tests. An acceptable error for linear measurement for clinical application was set as ≤ ±0.5 mm. Also, ≤ ±5° was deemed to be clinically acceptable for measuring systematic differences for angles[18].

Results

Seventy-five paired linear measurements (35 homolateral measurements and 40 contralateral measurements) at 0.12-mm voxels, thirty-one linear measurement (20 homolateral measurements and 11 contralateral measurements) at 0.3-mm voxels and 11 angles were evaluated in the present study. Intra- and inter-operator reliability using ICC was 0.961–1.000.

Linear measurements by 3D models from CBCT at 0.12-mm voxels (termed “CBCT1” in all Tables) and 0.3-mm voxels (CBCT2) demonstrated overestimates on homolateral and contralateral sides compared with the paired results using the digital caliper (Table I). The mean biases were 0.31±0.20 mm and

0.25±0.28 mm at 0.12-mm voxels, and 0.11±0.21 mm and 0.19±0.26 mm at 0.3-mm voxels. All 95% confidence intervals (CIs) were >0 mm but <0.5 mm. The only significant difference using the IOS relative to digital caliper pairs was observed on homolateral linear measurements. An equal amplification effect on sagittal and transverse directions was revealed by a one-sample *t*-test at 0.12-mm voxels and 0.3-mm voxels of CBCT with caliper measurements, whereas a significant increased enlargement was observed on the homolateral side using the IOS (Table I, II). In total, significantly larger results were observed compared with value obtained using digital caliper pairs. Also, results at 0.12-mm voxels using CBCT were significantly larger than all other values (Table IV) .

Angle measurements revealed good validity among the three digital methods compared with true values (Table III). Values for standard deviation and ranges of 95%CIs were large. Significant differences among the three digital models were not observed (Table IV).

Discussion

Superimposing orthodontic records at different time points has been used widely to determine the craniofacial changes. The cornerstone of superimposition is stable structure. Identification of stable structures in jaws without having external references in growing patients is extremely challenging. In history, metal implants have been used as reference in 2D cephalograms to explore natural stable structure [2,3]. In 3D era, implants should continually play a crucial role in CBCT [8,9,10] and digital dental model superimposition [14,15]. However，implants produce artifact both in CBCT and IOS image, which will degrade the image quality and bring errors. This preclinical study was to evaluate the reliability and validity of linear and angle measursments of 3D miniscrews on CBCT and IOS with actual values.

As our study revealed, statistically significant overestimations of linear measurements were obtained on CBCT both at 0.12 (0.27±0.24mm) and 0.3 (0.14±0.22mm) voxels compared with actual measurements. Our results are, to some extent, consistent with several studies. Moshfeghi et al.[19] using gutta-percha, reported an enlargement by 0.10±0.99 mm in axial section and 0.27±1.07 mm coronal section at 0.3 voxels. However, the values for standard deviation were greater than our data. Tolentino et al. [20] used silica markers, but they didn’t observe statistical difference among voxels at 0.25, 0.3 or 0.4 mm. These contradictory results may be owing to the different materials as references used in studies. Schulze et al. [21] pointed that an extreme artifact could be produced by titanium implants. Instead of upgrading resolution, they suggested a more sophisticated reconstruction algorithm for meaningful reduction of artifacts. Moreover, when using linear measurement to evaluate the stability of miniscrews, the systemtic error should be taken into consideration.

Secondly, miniscrews at two voxels presented reliable and accurate results on angle measurements with actual values. Our result supported it in clinical applications , which is important on measuring the angle stability of miniscrews after orthodontic loading[22].

On account of radiation exposure, CBCT is limited for evaluation of short-term treatment effects. Instead, chairside IOS is promising on this purpose. DeLong et al.[23]analyzed factors influencing IOS performance, and suggested that a smooth textured surface (such as the titanium miniscrews used in our study) could worsen the digitizing performance due to spectral reflection. However, our study confirmed the clinical reliability and validity of IOS for linear and angular measurements of miniscrews, which were consistent with other studies, but was different with respect to systematic errors and their tendencies [24,24,26,27,28,29]. Our result supported that the evaluation of tooth movement of serial digital dental models from IOSs during growth or after orthodontic intervention is operable. Apart from that, we also found it quite interesting that the mean bias on the homolateral side was significantly larger than that on the opposite, implying unequal magnification in sagittal and transverse directions. Anh et al. [30] claimed that regions imaged later would generate more errors during configuration than regions imaged earlier. Thus, the scanning sequence could be one of the reasons for the unequal amplification effect observed in our study, and a modification is required when miniscrews are involved.

Above all, in accordance with results of literatures and this study, several suggestions are proposed when miniscrews are used to superimpose 3D image:1.The positional stability of miniscrews should be evaluated firstly. 2. Same CBCT machine with same scanning setting are required. 3. Systematic errors of miniscrew measurements on CBCT image and digital dental model from IOS should be consider when the stable structures are explored.

However, our study had limitations. First, this is a In vivo experiment and we did not include the motion artifacts during imaging. Second, the study was conducted for a single experimental condition by testing systematic errors on a single type of miniscrew , a single CBCT machine and one IOS. Whether the results of this study are suitable for other miniscrews, other CBCT machines at different voxel sizes and other IOSs is not known.

Conclusions

1.The linear distance and angular measurement for minicrews seem reliable and clinically valid in images garnered by CBCT and an IOS as reference to measure tooth movements. However, when miniscrews are involved in high precision measurement in CBCT or IOS image, the systematic error should be taken into consideration.

2.Same voxels of CBCT images are suggested when miniscrews are set as reference to measure the changes in craniofacial structure in different time-points.

Declarations

Acknowledgments

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Ethics approval and consent to participate: we used 4 dead goats purchased from a poultry market in Beijing. According to previous similar studies,the use of such animal body parts requires no ethical regulation for in-vitro study.(Pal TM, Chakraborty A, Banerjee S. A micro-anatomical comparison of goat jaw cancellous bone with human mandible:Histomorphometric study for implant dentistry. journal of the international clinical dental research organization. 2014;6:20-3)

Consent for publication: “Not applicable”

Availability of data and materials: The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests: The authors declare that they have no competing interests

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Authors’ contribution: JYR and CG measured, analyzed and interpreted the data. JYR was a major contributor in writing the manuscript. All authors read and approved the final manuscript

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Tables

Table I. Paired *t*-test for comparing linear measurement values (mm) between the three digital models with values from the digital caliper.

Measurement	Mean bias	Standard deviation	95% confidence interval	t	P
Homolateral side					
CBCT1	0.31	0.20	0.24 to 0.38	9.111	<0.001
CBCT2	0.11	0.21	0.02 to 0.21	2.450	0.024
IOS	0.25	0.20	0.18 to 0.32	7.206	<0.001
Contralateral side					
CBCT1	0.25	0.28	0.16 to 0.34	5.637	<0.001
CBCT2	0.19	0.26	0.02 to 0.37	2.473	0.033
IOS	0.04	0.27	-0.04 to 0.13	0.986	0.330
Total linear measurements					
CBCT1	0.27	0.24	0.22 to 0.33	9.739	<0.001
CBCT2	0.14	0.22	0.06 to 0.22	3.505	0.001
IOS	0.15	0.26	0.09 to 0.21	5.106	<0.001

Table II. One sample *t*-test for comparing the differences in mean linear measurement (mm) between homolateral and contralateral sides of CBCT and IOS with measurements using the digital caliper (the test value was zero)

Measurement	Mean bias	Standard deviation	95% confidence interval	t	P
CBCT1	0.08	0.30	−0.01 to 0.19	1.714	0.093
CBCT2	−0.10	0.37	−0.35 to 0.15	−0.910	0.384
IOS	0.25	0.31	0.15 to 0.35	4.912	<0.001

Table III. Paired *t*-test for comparing angle measurement (°) values between the three digital models with actual measurements

Measurement	Mean bias	Standard deviation	95% confidence interval	t	P
CBCT1	0.11	1.97	−1.21 to 1.44	0.192	0.852
CBCT2	0.15	2.79	−0.88 to 1.19	0.330	0.748
IOS	0.41	2.34	−1.17 to 1.98	0.574	0.579

Table IV. Paired *t*-test for values of linear (mm) and angle (°) measurements among the three digital models

Measurement	Mean bias	Standard deviation	95% confidence interval	t	P
Linear measurements					
CBCT1–CBCT2	0.20	0.26	0.10 to 0.29	4.231	<0.001
CBCT1–IOS	0.12	0.24	0.07 to 0.18	4.434	<0.001
0.3-mm voxels–IOS	−0.02	0.32	−0.14 to 0.10	−0.363	0.719
Angle measurements					
CBCT1–CBCT2	−0.04	0.97	−0.69 to 0.61	−0.134	0.896
CBCT1–IOS	−0.29	2.79	−2.17 to 1.58	−0.346	0.737
CBCT2–IOS	0.49	1.20	−0.37 to 1.35	1.288	0.230

Figures

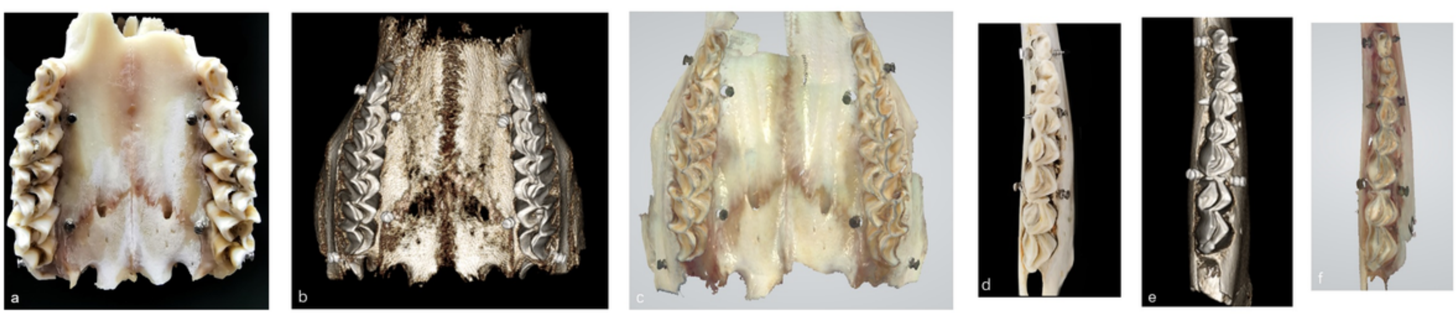

Figure 1

two representative images among 12 samples. b and e, 3D models originating from CBCT of the two actual samples on the left side. c and f, 3D models of the same samples on the left scanned from the IOS.

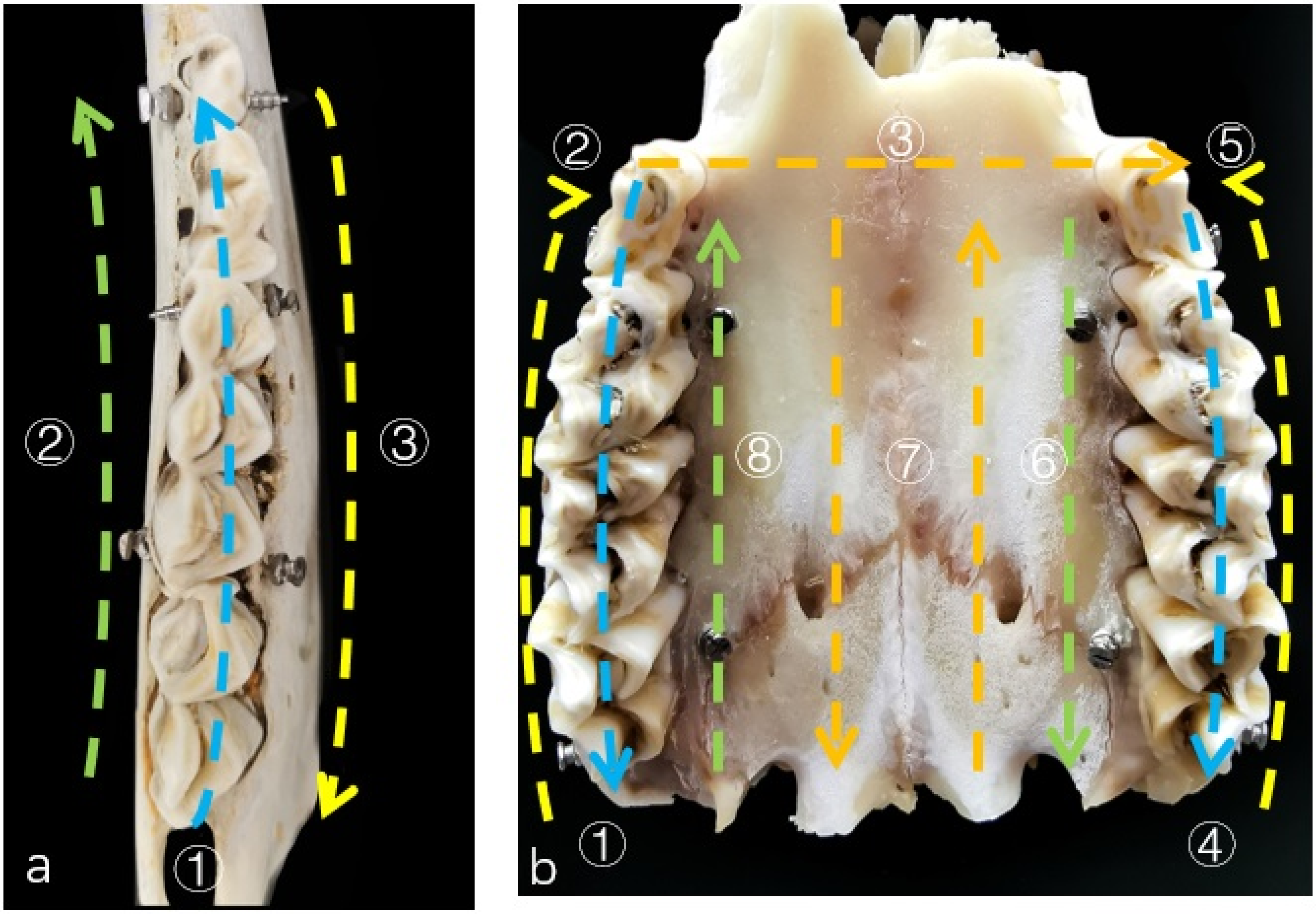

Figure 2

the imaging sequence of the IOS. a, representative imaging sequence for hemimandible samples: occlusal–buccal–lingual. b, representative imaging sequence for maxillary samples: right occlusal–right buccal–anterior palatal–left occlusal–left buccal–left palatal–palatal–right palatal.

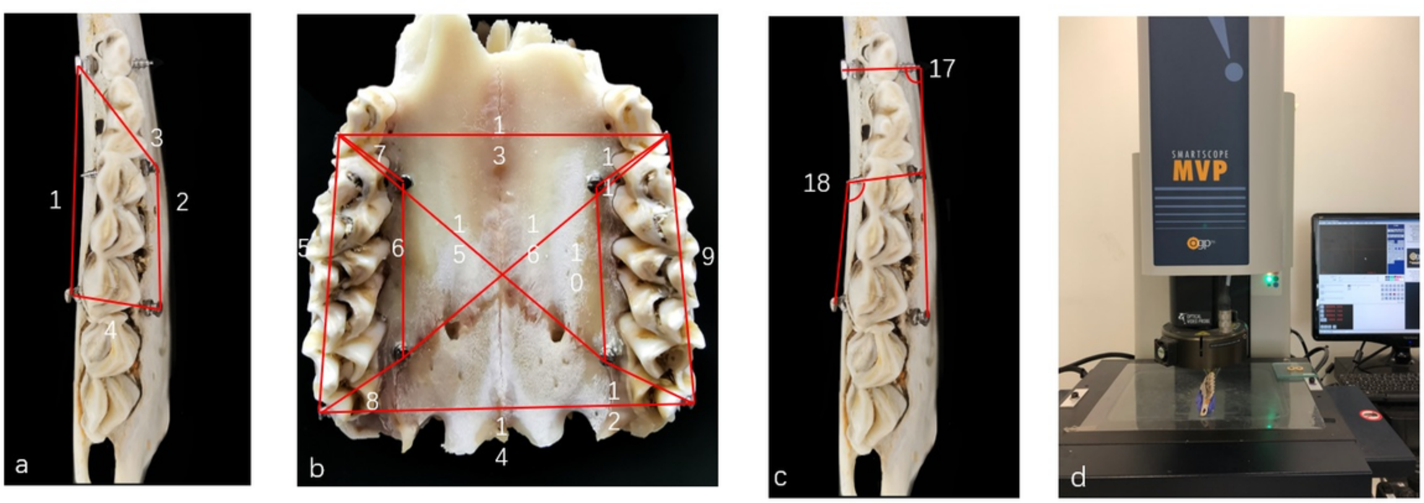

Figure 3

. a and b, 16 linear distances measured between two miniscrew heads on hemimandibles and maxillae. c, angles measured on the hemimandible. d, Smartscope MVP for actual measurement of angles.