Original Article

Cone-beam computed tomography for assessment of palatal displaced canine position
A methodological study

Julia Naoumova[a]; Heidrun Kjellberg[b]; Reet Palm[c]

ABSTRACT

Objective: To assess the inter- and intraexaminer reliability of a measurement method for evaluation of eruption angles and position of palatal displaced canines (PDCs) with cone-beam computed tomography (CBCT) images and to test the validity of the measured angles on a dry skull.

Materials and Methods: Twenty patients (eight boys, 12 girls; age 11.4 ± 1.2 years) were randomly chosen among 67 patients from a study evaluating the interceptive effect of extracting the deciduous canine in children with PDCs. In total, 60 images were analyzed, because each patient had three CBCT examinations (baseline, 6-month control, and endpoint). Two observers assessed the following measurements twice: mesioangular and sagittal angle, vertical position, canine cusp tip, and canine apex to dental arch. The validity of the angular measurements was tested against angular measurements on a dry skull using mathematical formulations.

Results: The inter- and intraexaminer mean differences for angular and linear measurements were all low and statistically insignificant ($P > .05$). The mean differences between the physical and 3D measurements were 0.5 ± 0.39 mm for the sagittal angle and 0.22 ± 0.19 mm for the mesioangular angle.

Conclusions: Linear and angular measurements on CBCT images are accurate and precise and can be used to assess the precise position of a PDC. (*Angle Orthod.* 2014;84:459–466.)

KEY WORDS: CBCT; Palatal displaced canines; Methodological study

INTRODUCTION

Diagnosis and treatment planning of palatal displaced canines (PDCs) has until recently been based on palpation in combination with conventional two-dimensional (2D) radiographs.[1] Since there are several disadvantages with 2D images, including distortion, inability to detect resorption of adjacent teeth, superimposition of structures, errors in projection, imaging artifacts, and variation in magnification, the application of computed tomography (CT) scanning has been suggested.[2–4]

Its clinical utility has been limited, however, because of the cost and the high radiation dose.[4] To address this, cone-beam computed tomography (CBCT) was introduced in the 1990s. The radiation doses are lower than with CT, which makes the CBCT an advantageous tool in dentistry.[5,6]

When a new technique such as CBCT is introduced, it is important to carry out methodological studies evaluating the technique's reliability and validity in order to make accurate measurements and treatment decisions and to assess the treatment effects. Several studies have investigated the accuracy and validity of measurements in CBCT mainly by comparing measurements performed on human skulls to anatomical structures that are commonly used in cephalometric

[a] Consultant Orthodontist, Research Fellow, Department of Orthodontics, Institute of Odontology at the Sahlgrenska Academy, University of Gothenburg, Göteborg, Sweden.

[b] Associate Professor, Department of Orthodontics, Institute of Odontology at the Sahlgrenska Academy, University of Gothenburg, Göteborg, Sweden.

[c] Employee Practitioner, Department of Oral and Maxillofacial Radiology, Sahlgrenska Academy, University of Gothenburg, Göteborg, Sweden.

Corresponding author: Dr Julia Naoumova, University of Gothenburg, Department of Orthodontics, Institute of Odontology at the Sahlgrenska Academy, Box 450, SE-405 30 Göteborg, Sweden
(e-mail: julia.naoumova@vgregion.se)

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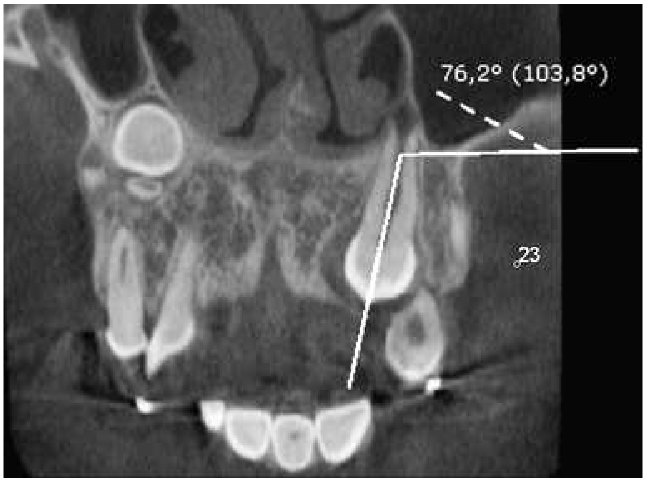

Figure 1. Mesioangular angle of PDC measured on a coronal view.

analysis. Overall, these studies show high accuracy and validity of linear[7,8] and angular measurements.[9] In addition, when the patient's head position was changed, it did not have any significant influence on linear measurements.[10] Moreover, the results of studies made on a cube,[11] an acrylic block,[12] or Plexiglas plates with metal spheres[13] show that measurements can be made with satisfactory results. Linear and angular measurements of the inclination and location of the impacted canines relative to the maxillary structures in three planes (coronal, sagittal, and axial) using the New Tom software have been previously described.[14,15] However, no studies have assessed the intra- and interexaminer reliability in localizing a PDC or tested the validity of the measurements. Because three-dimensional (3D) imaging systems have become a more popular option when analyzing the precise position of a PDC, it is of great importance to ensure that the validity and the reproducibility of the method are acceptable. The aim of this study was, thus, to evaluate the reliability and validity of measuring the precise position of a PDC using Accuitomo images in i-Dixel software.

MATERIALS AND METHODS

Twenty patients (eight boys, 12 girls; age 11.4 ± 1.2 years) were randomly chosen by using the simple randomization method from a sample of 67 patients from an ongoing study evaluating the interceptive effect of extracting the deciduous canine in children with a PDC. All patients had completed a CBCT examination on three occasions: at baseline and after 6 and 12 months of follow up, ie, in total, 60 CBCT images were analyzed. The patients and the inclusion and exclusion criteria are described in detail in a previous study.[16]

Children and parents received both verbal and written information about the study and were asked to sign the informed consent before entering the trial. The research ethics committee of Sahlgrenska Academy, Gothenburg, Sweden, approved the informed consent form and protocol (Dnr 578-08).

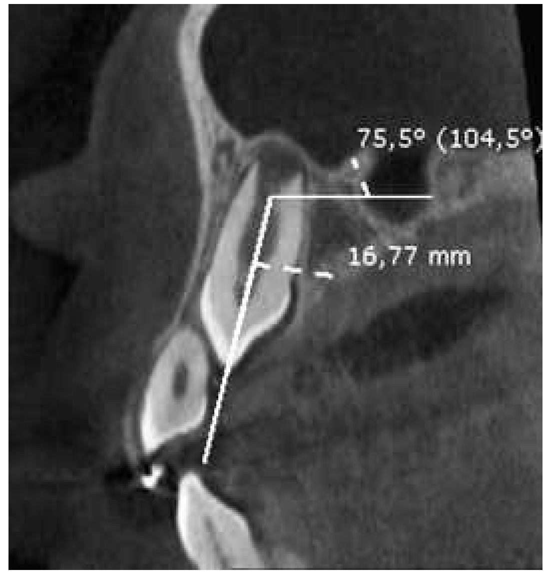

Figure 2. Sagittal angle and vertical position measured on a sagittal view.

Examination

The CBCT images were obtained with the 3D Accuitomo FPD (J Morita Mfg Corp, Kyoto, Japan) at a 360° rotation at the Clinic of Oral and Maxillofacial Radiology, University Clinics, Public Dental Service, Gothenburg. The volume used was 40 × 40 mm, and the examinations were made so that the teeth and tissues from incisors to the first molars were included in one volume.

Data Processing

Primary data reconstructions were made by acquisition software (i-Dixel-3DX, 3D Version 1.691; J Morita) at the Accuitomo workstation, providing axial, coronal, and sagittal views. A secondary reconstruction was made using i-Dixel software and DICOM export axial slices (slice thickness of 0.5 mm) that were then sent to the PACS workstation for later reformatting.

Workstation/Equipment

A workstation with Sectra IDSS (Sectraimtec AB, Linköping, Sweden) PACS Multi Planar Reconstructions was used for reformatting and viewing the axial slices. The workstation comprised a Dell computer (Optiplex GX620; DELL AB, Stockholm, Sweden) and three flat-panel monitors, one color and two monochromatic. All of the measurements were performed on

Figure 3. Distance from the canine cusp tip measured to the dental arch on an axial image.

one of the 20-inch monochromatic monitors (Eizo, RadiForces G20; EizoNano Corp, Ishikawa, Japan) with a resolution of 1600 × 1200 pixels.

Reliability on CBCT

Two independent observers carried out all the measurements. Both examiners underwent a calibration exercise of the measuring technique before starting. The hard palate was identified first, and a reference plane was drawn through the hard palate from the spina nasalis anterior to the posterior hard palate closure. This reference plane was then fixed, and thus never changed. Subsequent measurements were made relative to this plane. The canine was aligned, and a reference line was placed centrally along the tooth's longitudinal axis. Measurements were assessed in the following planes:

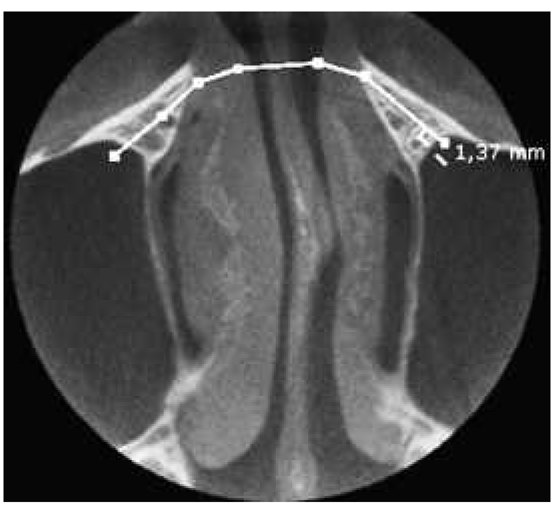

Figure 4. Root apex of the canine measured to the dental arch on an axial image.

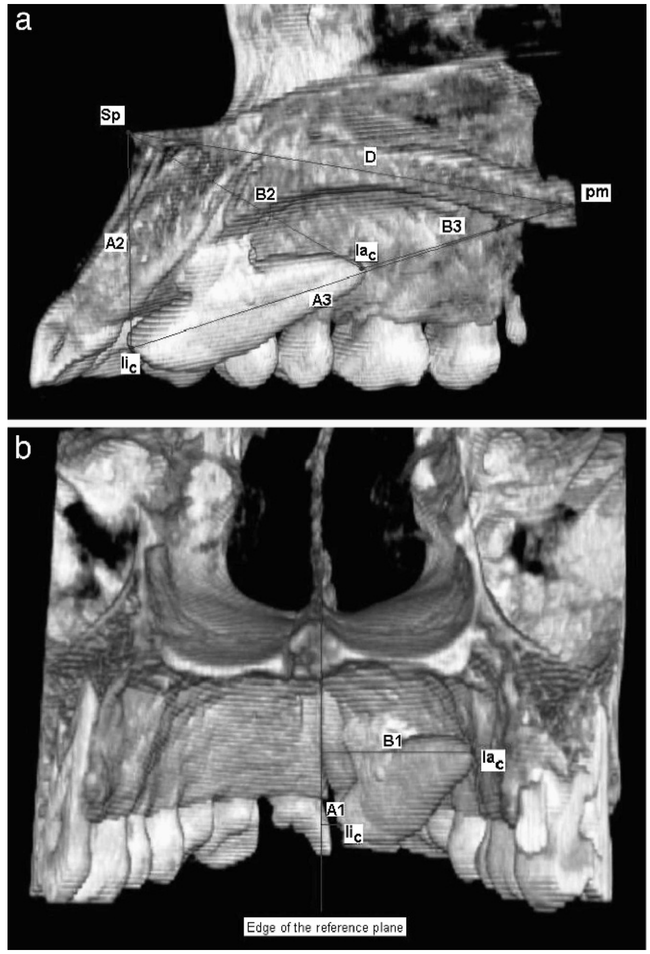

Figure 5a,b. 3D images of the dry skull with the direct measurements. Definitions are explained in detail in Table 1.

- Coronal plane: measurement of the *mesioangular angle* relative to the reference plane (Figure 1).
- Sagittal plane: measurement of the *sagittal angle* relative to the reference plane and the vertical position from the reference plane to the incisal edge of the canine (Figure 2).
- Axial plane: measurement of the *canine cusp tip and canine apex* to a line that is drawn in the center of the dental arch from tooth number four (54, 14, 64, or 24), where the marginal bone is visible interdentally on teeth 11/21 (Figures 3 and 4).

Validity on Dry Skull

To test the validity of the measured angles, an extracted permanent canine was placed in the palate of a dry skull in three different angulations and positions that corresponded to the PDCs examined in the patients. CBCT images were taken that represented each of the three occasions by placing the dry skull on a stand so it could be positioned, as though it were

Table 1. Definitions and Abbreviations of Direct Measurements Made on the Dry Skull

Measurements	Abbreviation	Definition
Reference plane: spina nasalis (sp) to pterygomaxillare (pm)	sp-pm (D)	Distance in mm from spina nasalis to pterygomaxillare
Ii_c (incisal edge of the canine) to reference plane	Ii_c-RP (A1)	Perpendicular distance in mm from Ii_c and reference plane
Ii_c to spina nasalis (sp)	Ii_c-sp (A2)	Distance in mm from Ii_c to sp
Ii_c to pterygomaxillare (pm)	Ii_c-pm (A3)	Distance in mm from Ii_c to pm
Ia_c (apex of the canine) to the reference plane	Ia_c-RP (B1)	Perpendicular distance in mm from Ia_c and reference plane
Ia_c to spina nasalis	Ia_c-sp (B2)	Distance in mm from Ia_c to spina nasalis
Ia_c to pterygomaxillare	Ia_c-pm (B3)	Distance in mm from Ia_c to pm

a patient's head. One observer assessed both the dry skull measurements and the measurements on the 3D images. Seven direct linear measurements were measured on the dry skull (Figure 5; Table 1) with a digital calipers (resolution 0.01 mm; accuracy ±0.03 mm for distances 100–200 mm; ClasOhlson, Sweden AB, Insjön, Sweden). These measurements were used for calculating the angles in Microsoft Excel with the following methods:

Sagittal angle calculation. Several mathematical formulations were needed to calculate the sagittal angle. These are thoroughly described in the legends of Figures 6 and 7.

Mesioangular angle calculation. Geometrical illustration and stepwise mathematical explanation of how the mesioangular angle was determined are shown in Figure 8.

Repeat Measurements

To determine the systematic errors of the intra- and interexaminer analyses, all 60 images were remeasured by the two operators after 2 weeks to eliminate memory bias. To avoid operator fatigue, no more than ten 10 images were analyzed at one time. All lines and reference planes were redrawn between the first and the second measurements. The direct measurements on the dry skull and the images taken on the skull were measured three times at intervals of at least 2 days. The mean values of these three

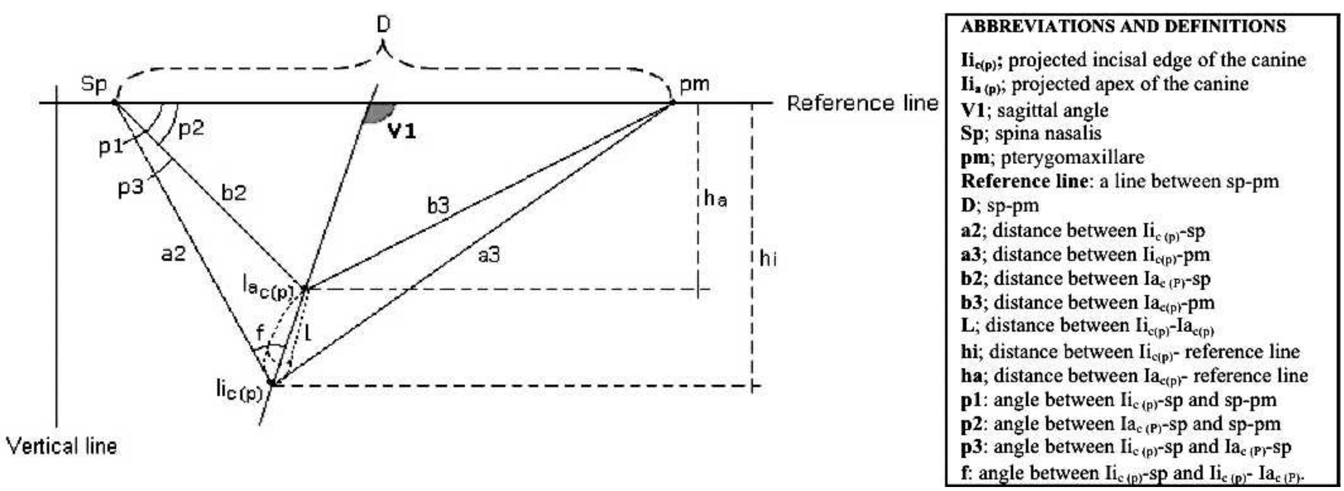

Figure 6. Illustration of how the sagittal angle (V1), corresponding to the sagittal angle in Figure 2, was determined by projecting the canine (dotted drawing) on the reference line in a 2D plane. Thus, the measurements A2 (Ii_c-sp), A3 (Ii_c-pm), B2 (Ia_c-sp), and B3 (Ia_c-pm) (Table 1) were projected onto the reference plane. The reference plane is an imaginary plane constructed using the reference line, which is a horizontal line between the spina nasalis (sp) and pterygomaxillare (pm) and a vertical line. Using this projection, a line passing through $Ii_{c(p)}$ and $Ia_{c(p)}$ was created. Lines were then drawn from $Ii_{c(p)}$ and $Ia_{c(p)}$ to sp and pm. The next step was to determine the projection of the line a2 ($Ii_{c(p)}$-sp) (Figure 8). All the distances, a3 ($Ii_{c(p)}$-pm), b2 ($Ia_{c(P)}$-sp), and b3 ($Ia_{c(p)}$-pm), were obtained in a similar way. To find the sagittal angle, the angles p1, p2, p3, and f and the distance x ($Ii_{c(p)}$-$Ia_{c(p)}$) had to first be determined. As the distances a2 ($Ii_{c(p)}$-sp), a3 ($Ii_{c(p)}$-pm), and D (sp-pm) have been previously obtained, the angle p1 was calculated using the Law of Cosines: $\cos(p1) = (D^2 + a2^2 - a3^2)/(2 \times D \times a2)$. The distances b2, b3, and D were used for calculation of the angle p2 using the Law of Cosines. The angle p3 was obtained by subtracting p2 from p1. The Law of Cosines was also used in the determination of the distance x: $x^2 = a2^2 + b2^2 - [2 \times a2 \times b2 \times \text{Cos}\ (p3)]$. Angle f was then calculated using the following formula: $\cos(f) = (a2^2 + x^2 - b2^2)/(2 \times a2 \times x)$. The sagittal angle was obtained by summing up the angles p1 and f. Abbreviations and definitions are shown on the right side.

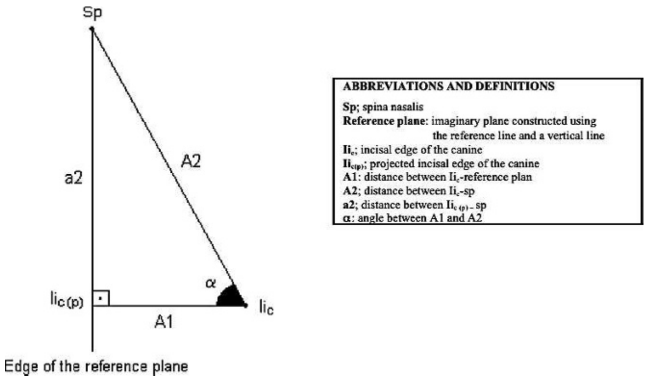

Figure 7. The triangle illustrates how the projection of line a2 ($Ii_{c(p)}$-sp) on the reference plane was determined. As the distances A1 (Ii_c-reference plane) and A2 (Ii_c-sp) were already known by the direct measurements made on the dry skull, the α angle was calculated using the trigonometric equation $\cos(\alpha) = (A1/A2)$. The α angle was then used in the equation $\tan(\alpha) = (a2/A1)$ to calculate distance a2. Abbreviations and definitions are shown on the right side.

measurements were used for the descriptive statistics. The direct measurements were done before the radiographs were taken.

Statistics

Descriptive statistics with mean values and standard deviations were calculated for each reliability and validity measurement. Random error was calculated by using the standard deviation of a single measurement according to Dahlberg[17]: $s = \left(\sum d^2/2n\right)^{1/2}$, where d = the difference between duplicate determinations and n = the number of determinations. The confidence interval for both the intra- and interexaminer measurements was also assessed. The systematic error was examined using the Student's paired sample *t*-test at $P < .05$. Statistical analyses were carried out using SPSS (version 15.0; SPSS Inc, Chicago, Ill).

RESULTS

Reliability: On CBCT

The mean and standard deviation differences, *P* values, and confidence intervals for interexaminer measurements are shown in Table 2; those for intraexaminer measurements are in Table 3. The mean differences of all angular and linear measurements were low and statistically insignificant for both inter- and intraexaminer measurements.

Validity: On Dry Skull

Comparisons of angular measurements made on CBCT with the physical measurements on the dry skull are shown in Figure 9. The mean differences between them were $0.51^\circ \pm 0.39^\circ$ for the sagittal angle and $0.22^\circ \pm 0.19^\circ$ for the mesioangular angle. No significant differences were found between physical and 3D measurements either for the sagittal or for the mesioangular angle.

DISCUSSION

CBCT has become exceedingly popular among orthodontists worldwide and is increasingly used for diagnosis and treatment planning. Methodological

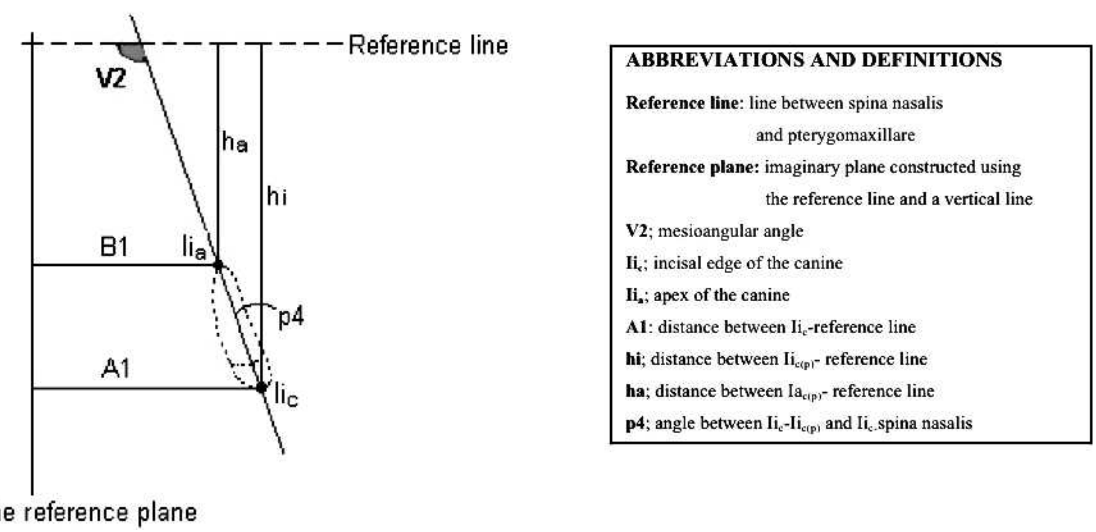

Figure 8. Illustration of how the mesioangular angle (V2) corresponding to the mesioangular angle in Figure 1 was obtained. The dotted drawing indicates the canine. The distances hi ($Ii_{c(p)}$-(sp-pm)) and ha ($Ia_{c(p)}$-(sp-pm)) and the angle p4 were needed for the calculation of V2. As the distances A1 (Ii_c-RP) and B1 (Ia_c-RP) would have already been measured from the dry skull, the following equations were used to calculate the distances hi and ha: $hi = \sin(p1) \times a2$, and $ha = \sin(p2) \times b2$. To calculate the angle p4, the tangent equation was used: $\tan(p4) = (A1 - B1)/(hi - ha)$. The mesioangular angle was obtained by summing up the angle p4 with 90 degrees. Abbreviations and definitions are shown on the right side.

Table 2. Mean and Standard Deviation Differences, *P* Values, and Confidence Intervals of the Interexaminer Measurements[a]

	Interexaminer							
	Observer 1				Observer 2			
	Mean Difference	SD of Difference	*P**	CI	Mean Difference	SD of Difference	*P**	CI
Angular measurements, °								
Mesioangular angle	−0.32	0.82	.16	−0.77 ± 0.13	0.35	0.47	.09	−0.05 ± 0.76
Sagittal angle	0.35	0.41	.15	−0.75 ± 0.12	0.53	0.55	.10	−0.12 ± 0.19
Linear measurements, mm								
Vertical position	−0.14	0.39	.18	−0.35 ± 0.06	−0.05	0.33	.58	−0.23 ± 0.13
Canine cusp tip to dental arch	0.25	0.33	.09	−.03 ± 0.33	−0.27	0.29	.39	−0.23 ± 0.09
Canine apex to dental arch	−0.27	0.37	.48	−0.28 ± 0.13	−0.23	0.56	.39	−0.45 ± 0.18

[a] SD indicates standard deviation; CI, confidence interval.
* $P < .05$ is considered significant.

studies are, therefore, of importance for evaluating its reliability and validity before applying the method clinically. The present study evaluated the reliability and validity of CBCT to measure the precise position of PDCs using a coordinate system on 3D images with the i-Dixel software. The overall in vivo CBCT measurements were highly accurate and reproducible, with less than one measuring unit (mm or degree) of difference, which is the magnitude of clinical significance for radiographic measurements mentioned in the literature.[18,19] No significant differences were found for intra- or interexaminer measurements, but higher interexaminer error was observed, as has also been shown in previous studies.[20–22] *Canine cusp tip to dental arch* and *canine apex to dental arch* had somewhat higher measuring errors compared to the rest of the linear measurements in both intra- and interexaminer measurements. This can be explained by the following geometric principle that Nagasaka et al.[22] illustrated in his study: the distance between landmarks influences the magnitude of measuring errors of linear measurements. They showed that the closer two landmarks are, the greater the linear measurement error tends to be.[22] As mentioned in the "Materials and Methods" section, CBCT images from 20 patients on three different occasions were measured instead of measuring 60 images on one occasion, since that was the original design of the study. This might have resulted in a greater variation of canine apex development or position of the canine cusp tip, which can be another explanation for the somewhat higher errors in these variables.

Many previous studies have assessed the validity of linear measurements by comparing measurements made on an object (ie, cube, acrylic block, or Plexiglas plates with metal balls) with radiographic measurements or direct caliper measurements on human skulls vs those made on CBCT scans using multi-planar reconstruction images (ie, axial, sagittal, and coronal sections). The overall conclusion of these investigations is that CBCT measurements are highly accurate and reproducible.[7–13,24] Moreover, the artificial measurements had higher accuracy and precision than measurements made on patients; in some cases less than the voxel size (0.125 mm), which can be explained by anatomical structures being more difficult to define.[13,24] However, studies evaluating the validity of angular measurements are limited. Therefore the in vitro part of this study evaluated only the validity of angular measurements.

Table 3. Mean and Standard Deviation Differences, *P* Values, and Confidence Intervals of the Intraexaminer Measurements[a]

	Intraexaminer			
	Mean Difference	SD of Difference	*P**	CI
Angular measurements, °				
Mesioangular angle	−0.01	0.27	.94	−0.26 ± 0.24
Sagittal angle	0.01	0.47	.96	−0.33 ± 0.35
Linear measurements, mm				
Vertical position	−0.01	0.09	.98	−0.13 ± 0.13
Canine cusp tip to dental arch	0.13	0.18	.60	−0.10 ± 0.17
Canine apex to dental arch	0.11	0.13	.95	−0.15 ± 0.16

[a] SD indicates standard deviation; CI, confidence interval.
* $P < .05$ is considered significant.

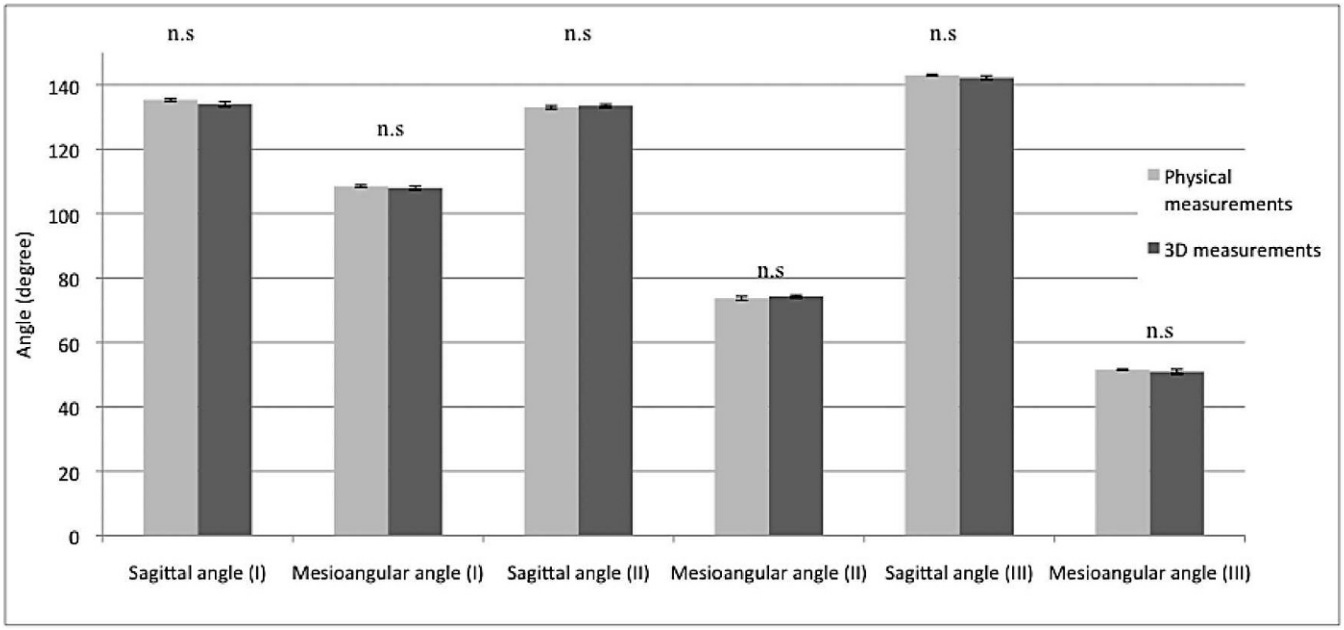

Figure 9. Mean values and standard deviations of sagittal and mesioangular angles on different occasions obtained by physical and 3D measurements. n.s indicates nonsignificant difference.

Measurement accuracy is affected by the method that is used. Factors such as the precision of the caliper and software are important, but size, material, and the resolution of the images can also influence the study results.[25] In our study, we used a caliper that offered measurements made to the nearest 0.01 mm, and the images had higher resolution capability with 0.5-mm slice thickness, which was greater than most previously published studies.[15,18–21] Furthermore, the i-Dixel software we used has been validated for various purposes by other studies in the orthodontic field.[13,24]

When a specific radiographic examination is chosen, it is important to consider factors including the probability of obtaining the diagnostic information that is sought from it, its risks, and the costs.[23] In order to reduce the radiation dose from the CBCT scans in this study, we used volumes of 40 $\times$ 40 mm, which gives an effective dose of 0.025 mSV. This can be compared with the doses that may be received from 1 week of cosmic background radiation. Even if the amounts of radiation dose are the same, the DNA damage is higher in a shorter time of exposure; therefore, the ALARA (As Low As Reasonable Achievable) principle must be followed.

CONCLUSIONS

- Linear and angular measurements on CBCT images are accurate and precise and can be used to assess the exact position of palatal displaced canines.
- The validity of angular measurements that were tested against angular measurements on a dry skull, using the law of cosine, was of a high level.

ACKNOWLEDGMENTS

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