Reproducibility of radiographs with the Orthopantomograph 5: Tooth-length assessment

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The precision of tooth-length assessments based on repeated panoramic radiographs made with a Siemens OP 5 was investigated in three groups of twenty patients. Two exposures of the same patient were made under three different radiographic conditions. Of the tooth lengths, nonmeasurability was found in 14% to 17%. The variability (standard deviation) of the measurements assessed from repeated radiographs ranged from 0.65 to 0.85 mm, or 2.4% to 3.1% of the mean radiographic tooth length in the different patient groups. The measurement error ranged from 0.43 to 0.56 mm, indicating that the main source of error inherent in the method was recognition of the reference points. Small differences were found between the tooth groups and between the right and left sides.
(ORAL SURG. 58:736-741, 1984)

In the extensive literature on panoramic radiography few reports deal with the reproducibility of the technique. This is to be expected, since a great disadvantage to the use of such equipment has been the lack of a satisfactory head-positioning device. For various panoramic machines, such as the Panorex[1] and the Orthopantomograph,[2-5] special cephalostats were therefore developed in the 1960s. It was suggested that longitudinal studies with such units might be possible.

During the last decade the image distortion inherent in rotational panoramic radiography has been discussed in several theoretical and experimental works. Using a mathematical model, Welander[6] demonstrated in 1974 that the image produced is composed of two central projections acting simultaneously, one in the vertical dimension and one in the horizontal. The vertical dimension in the image is dependent on a projection that has the x-ray source as the focus, that is, an ordinary central projection. The horizontal dimension, depending on a projection that has the rotation center of the beam as the effective focus, is affected by the speed of the film in relation to that of the beam. At the center of the sharply depicted layer, the magnification factor is the same in both dimensions.[6]

All characteristic distortion effects inherent in this specific technique are due to the different magnification factors which are valid for the vertical and horizontal dimensions outside the center of the sharply depicted layer.[7] The magnification factor varies relatively little in the vertical dimension.[8] In the horizontal dimension, on the contrary, the magnification factor varies in such a way that the *increase* is more marked when the object is displaced toward the *rotation center of the beam* than is the *decrease* when the object is displaced toward the *film*.[6] The horizontal magnification factor is most variable in regions where the effective projection radius is shortest and the image layer thinnest, that is, in the anterior jaw region.[6, 9, 10] From such considerations it was stressed by Tronje and associates[11] that horizontal assessments of linear dimensions are

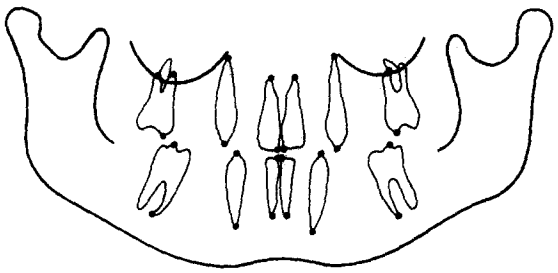

Fig. 1. Schematic drawing of part of panoramic film indicating the reference points for estimation of the maximum tooth lengths.

Table I. Age and sex distribution and digital display (reference number of head positioner) recording of the three groups of twenty patients examined with the Orthopantomograph 5

*Patient groups**	*Number of patients*		*Age of patients (yr)*		*Digital display recording (one unit corresponds to 1 mm)*	
	Female	*Male*	*Mean*	*Range*	*Mean*	*Range*
I	8	12	19.2	9-36	34.7	24-41
II	11	9	23.5	8-65	37.6	25-45
III	10	10	33.3	10-73	36.8	29-45
Total	29	31	25.3	8-73		

*Group I: Two exposures were made by the same radiographer, operating with identical digital display and kVp settings.
Group II: Two exposures were made by different radiographers, also operating with identical display and kVp settings.
Group III: Two exposures were made by different radiographers, operating with identical kVp setting, and the second operator did not know the digital display recording of the first one.

Table II. Number of teeth* studied with respect to maximum tooth-length assessment on panoramic films made with the Orthopantomograph 5

Patient groups†	*No. of tooth length (percent in parentheses)*		
	Total	*Measurable*	*Nonmeasurable*
I	238	198	40 (16.8)
II	228	195	33 (14.5)
III	218	187	31 (14.2)

*Tooth groups: Maxillary and mandibular first molars, canines, and central incisors.
†For definition of patient groups, see Table I.

Table III. Mean radiographic tooth lengths and standard deviations (SD) of measurements (in mm) on panoramic films made with the Orthopantomograph 5

*Patient groups**	*Observer*	*N*	*Mean*	*SD*
I	1	198	27.25	4.17
	2	198	27.32	4.34
II	1	195	27.01	4.39
	2	195	26.98	4.22
III	1	187	27.12	4.49
	2	187	27.30	4.32

*For definition of patient and tooth groups, see Tables I and II, respectively.

unreliable in panoramic films. Vertical measurements, on the other hand, may be reliable if the patient has been properly positioned in the machine during exposure. A prerequisite is also that the individual does not differ too much from the average jaw presumed in the design of the unit.

On new models of panoramic machines, various devices have been constructed to ensure that the patient's head is in the same position at repeated exposures. The Orthopantomograph 5 has, among other details, a special motor-driven head positioner with a digital display. At the Department of Oral Radiology, Dental Faculty, University of Oslo, such a machine had been in use for about 6 months when studies on the reproducibility of panoramic films in practical-clinical work were initiated.

The aim of this study was to investigate (1) the precision of measurements of vertical dimensions (that is, tooth lengths) in different jaw regions based on repeated panoramic exposures and (2) the possible influence of the digital display recording on this precision.

MATERIALS AND METHODS

The Orthopantomograph 5 (hereafter called the OP 5) tested in this study was operated by four trained radiographers. The operating procedure was performed as described in the operating instructions. Siemens special screens were used. The only requirement specified in advance regarding patient selection was that the patient should have a complete or almost complete dentition and be able to bite into the notches of the standard bite block. All orthopantomograms were made during a 4-month period.

To investigate the importance of recording the reference number of the head positioner (digital display) as an aid in repositioning the patient in the machine for another exposure, two separate exposures of three patient groups (I, II, and III), that is, six series of panoramic films, were evaluated. Each patient group comprised twenty subjects; age and sex distribution is given in Table I. In Group I, two exposures were made by the same radiographer, operating with identical digital display and kVp settings. In Group II, two exposures were made by different radiographers, also operating with identical digital display and kVp settings. In Group III, two exposures were made by different radiographers, operating with identical kVp setting, and the second

Table IV. Mean differences and standard deviations (SD) between tooth-length assessments (in mm) on repeated panoramic films made with the Orthopantomograph 5

	Tooth region								
	First molars (right)			*Canines (right)*			*Central incisors (right)*		
*Patient groups**	*N*	*Mean difference*	*SD*	*N*	*Mean difference*	*SD*	*N*	*Mean difference*	*SD*
I Maxilla	15	−0.08	0.45	17	−0.07	0.50	16	0.04	1.40
Mandible	20	−0.16	0.67	18	0.25	0.74	11	0.22	0.91
II Maxilla	18	0.30	0.54	17	−0.11	0.62	14	0.07	0.52
Mandible	17	0.05	0.43	19	0.10	0.85	12	0.01	0.69
III Maxilla	15	0.04	0.41	16	0.49	0.86	17	−0.06	0.72
Mandible	18	0.12	0.28	19	0.49	0.89	8	−0.13	0.52

*For definition of patient groups, see Table I.

Table V. Mean differences and standard deviations (SD_R) between tooth-length assessments (in mm) on repeated panoramic films made with the Orthopantomograph 5; measurement error (SD_S) based on double readings on the same films

*Patient groups**	*N*	*Mean difference*	*SD_R (percent of mean radiographic tooth length in parenthesis)*	*SD_S*
I	198	−0.11	0.85 (3.1)	0.56
II	195	+0.07	0.65 (2.4)	0.49
III	187	+0.16	0.74 (2.7)	0.43

*For definition of patient and tooth groups, see Tables I and II, respectively.

operator did not know the digital display recording of the first one.

Prior to the second exposure, the patient was removed, the apparatus was reset and, as a rule, another patient was examined before the repeated exposure was made.

Each series of orthopantomograms was evaluated on separate occasions. The first series of each patient group was measured by two observers independently, and the measurements were repeated by one of the observers after a period of approximately 1 week.

In the first part of the study twelve tooth lengths in the maxilla and the mandible were measured on each film. The maximum length from the apex to the most incisal/occlusal point was assessed, as illustrated in Fig. 1. Before the measurements were made, each pair of radiographs was compared, with particular attention paid to the recognition of the apical reference points. In cases where these points were uninterpretable in one film of a pair, reference points in both films were excluded. Still it was necessary to mark some of the remaining reference points with a pencil because of difficulties with their recognition. The number of uninterpretable dimensions, together with those marked apically, was noted from each panoramic film. The evaluation was repeated after approximately 1 week. The agreement was considered satisfactory if this evaluation did not differ more than one dimension (uninterpretable or marked) from the first evaluation. All measurements were read by means of a modified AGA Geotracer mounted on an illuminator with adjustable light intensity. The viewing lens in the reading head of the Geotracer had a magnifying factor of 2.5. The digitized data collected were stored as data files and later retrieved and processed by a Zilog System MCZ computer.

In the second part of the study each film pair was reviewed and pinholes were placed, under optimal illuminating conditions, to mark the reference points. The first film was used as a visual reference for placing the pinholes in the second film. Only reference points for which no doubt existed as to their recognition on both films were included.

RESULTS

The incidence of nonmeasurable tooth lengths varied between 14% and 17% (Table II). About one half of these occurred in the mandibular anterior region. The other half was distributed among the other tooth groups except in the mandibular molar region, where all teeth present could be measured. Of all dimensions, it was considered necessary to mark 13%-17% mostly in the maxilla, apically. The repeated nonmeasurability/marking procedure showed 90% intraobserver and interobserver agreement with the first evaluation.

Small differences were found between the observers concerning the mean tooth lengths and standard deviations (Table III).

The mean differences and standard deviations

Central incisors (left)			*Canines (left)*			*First molars (left)*		
N	*Mean difference*	*SD*	*N*	*Mean difference*	*SD*	*N*	*Mean difference*	*SD*
16	0.02	0.44	18	−0.88	1.62	14	−0.29	0.54
15	0.20	0.75	18	−0.37	0.73	20	0.16	0.34
17	−0.04	0.47	18	−0.02	0.92	16	0.11	0.63
11	−0.01	0.55	19	0.54	0.82	17	0.14	0.42
13	−0.07	0.84	16	0.40	1.02	18	0.19	0.36
9	0.44	0.66	19	−0.18	1.17	19	−0.07	0.39

Table VI. Mean differences and standard deviations (SD) between tooth-length assessments (in mm) on repeated panoramic films made with the Orthopantomograph 5

*Patient groups**	*N*	*Mean tooth length (first exposures)*	*Mean difference between first and second exposures*	*SD† (percent of mean tooth length in parentheses)*
I	120	27.90	+0.03	0.26 (1.0)
II	112	27.37	+0.08	0.35 (1.2)
III	120	27.54	+0.05	0.38 (1.4)

Pinholes were placed to mark the best-defined reference points.
*For definition of patient and tooth groups, see Tables I and II, respectively.
†Measurement error was 0.07 mm.

assessed from repeated exposures showed small variations in the different tooth groups and between the right and left sides (Table IV).

In all three patient groups, the mean difference of the tooth lengths between repeated exposures was close to zero (Table V). The variability, expressed in standard deviations, also showed small differences between the groups, ranging from 2.4% to 3.1% of the mean length. The uncertainty of tooth-length assessments was mainly due to the readings on the films (Table V). The assessments of tooth lengths precisely marked with pinholes confirmed the small variability of the dimensions caused by the repositioning of the patient in the machine (Table VI).

DISCUSSION

Reproducibility testing of panoramic machines is of great importance: first, because rotational panoramic radiography is widely used in clinical work and comparison between examinations made of the same patient at different occasions is often necessary and, second, because there is a need for reliable panoramic radiography in longitudinal studies, as has been emphasized by previous authors, such as Zach and associates.[5] To our knowledge, no previous report has attempted to quantify the precision on the basis of repeated exposures without specially designed cephalostats.[1,2]

Much attention has been focused on the unreliability of measurements in the horizontal dimension of the panoramic image. The variability of such measurements assessed from repeated exposures has proved to be higher[2,4,5] and the accuracy is known to be lower[11,12] than in the vertical dimension. Therefore, the present study was limited to an assessment of vertical or nearly vertical dimensions, (that is, tooth lengths).

Measurements cannot be performed in regions with evident unsharpness or distortion of the image. In the present study these effects lead to nonmeasurability, particularly in the mandibular anterior region. If desirable, this information could have been used to adjust the position of the patient for a retake in order to obtain more frequently a correct image of this region.[12] The sharply depicted layer, being highly dependent on the effective projection radius (see Introduction), is thinner in the anterior region than in the lateral region. The observed uninterpretability is therefore not unexpected and is in agreement with previous studies.[13,14] Examining films made with the Orthopantomograph 3 (OP 3), among other machines, Stenström and colleagues[14] found that

uninterpretable apical areas comprised 57% of all teeth examined. However, this figure should not be directly compared to that obtained in the present study in which only dimensions, not periapical diagnosis, were evaluated. In addition, a selection of tooth groups was made. The sharply depicted layer in the front region is also thicker with the OP 5 than with the OP 3.

Although 14% to 17% of the studied tooth dimensions had to be excluded, difficulties were experienced in recognizing several of the reference points; it was considered necessary to mark up to 17% apically. Still, measurements on repeated exposures showed that 5.5%, 3.6%, and 7.5% of the differences found in Groups I, II, and III, respectively, exceeded 2 mm. Similar figures were obtained for the repeated measurements on the same film. Re-examination of the film pairs showed that different reference points had been used for assessing the dimensions. In clinical situations in which direct comparisons between panoramic films taken on different occasions are made, such errors will probably be reduced. When excluding differences exceeding 2 mm, the standard deviation based on repeated exposures decreased to about 0.5 mm (measurement error, 0.4 mm) or 2% of the mean radiographic tooth length. By comparison, a corresponding standard deviation of 0.39 mm (measurement error, 0.26 mm), or 1.7% of the mean tooth length, was found by Eggen[15] from measurements on intraoral paralleling radiographs. Since 95% of the individual observations are expected to fall within ± 2 standard deviations, this interval may be used as a measure of the practical error limits.[16] This means that root resorption of about 1.5 to 2 mm, for instance, should be possible to observe in longitudinal examinations using the present panoramic method (with the reservations discussed). The degree of root resorption after orthodontic treatment with fixed appliances was studied by Sjölien and Zachrisson,[17] who found differences in mean tooth length between treated and untreated subjects ranging from 1.2 to 1.8 mm in the maxillary anterior region. In another study on orthodontically treated patients, Hollender and associates[18] found that in about 12% of the teeth with resorption, this was equal to or greater than 2 mm. In order to be able to identify cases in which there is a greater risk of substantial root resorption, panoramic radiography might be a convenient method because of its advantages as a simple screening procedure with low patient dose.

The present study showed that the precision of tooth-length assessments on films from the OP 5 was insignificantly improved, even if the same radiographer (Group I) made repeated exposures with the forehead support in identical position, as compared to exposures made by different radiographers (Groups II and III), who accurately followed the operating instructions. This was valid also when calculations were made with dimensions precisely marked with pinholes. The distribution of the digital display recording was rather similar in the different groups (Table I). In Group III, the mean difference of this recording between the two radiographers was 6.1 mm (SD 3.2), although a difference of up to 14 mm was registered. Thus, in most patients the radiographers arrived at a rather similar position of the forehead support when following the instructions.

The only variable exposure parameter when the OP 5 was used—the kVp—was identical during all repeated exposures. The radiographic density should be kept as constant as possible when radiographs of the same patient are compared. In the present study the small differences in density observed between the repeated films probably had no influence on the tooth-length assessments.

The rather small variability in the tooth length observed at repeated exposures was not unexpected. According to Tronje and co-authors,[11] the panoramic film may be used for vertical measurements, provided that the patient has been properly positioned in the machine during the exposure. In a successive article on reproducibility of panoramic films with the OP 5, the precision of horizontal measurements will be determined and compared to that assessed in the vertical dimension.

CONCLUSIONS

Reproducibility testing of vertical dimensions (that is, tooth lengths) in various jaw regions on repeated panoramic films of sixty patients examined with the Orthopantomograph 5 according to the operating instructions showed:

1. Nonmeasurability was found in 14% to 17% and marking of apical reference points was considered necessary in 13% to 17%.
2. Of the dimensions measured, the variability at repeated exposures showed small differences between the tooth groups and between right and left sides.
3. Small differences were also found, whether or not the digital display (reference number of the head positioner) was used as an aid in repositioning the patient for another exposure.

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