



Dimensional Accuracy and Details of the Panoramic Cross-sectional Tomographic Images: An *in vitro* Study

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ABSTRACT

Introduction: Transversal slicing system (TSS) of Planmeca PM 2002 CC is a tomographic technique which enables us to take cross-sectional views of jaws. Tomographic imaging modalities are commonly applied to acquire cross-sectional images of the jaws for preimplant assessment of bone. Among the available tomographic imaging modalities, panoramic radiography is the most accessible imaging system.

Materials and methods: Study was conducted using 25 mandibles, out of these five were used for linear dimensional accuracy measurement and the rest 20 were utilized to study the details within the mandible. Study was aimed to evaluate dimensional stability in the images using different parameters, such as determination of direction of slice, determination of horizontal and vertical magnification, angular distortion, three-dimensional distortion and determination of details.

Results: For the direction of slice and for determination of horizontal and vertical magnification change in $+5^\circ$ to -5° was in acceptable limit. In determination of details, it was found that there was great discrepancy in readings given by nonradiologist which offset the mean value which was attributed to lack of training for interpretation of the observers.

Conclusion: 99% of the readings were in the clinically acceptable limits.

Clinical significance: The easy availability, use of routine equipment, the low cost, low radiation dose for cross-sectional radiography make the TSS most preferred modality.

Keywords: Cross-sectional radiography, TSS system, PM, 2002 CC, Panoramic radiography.

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INTRODUCTION

The placement of dental implants is an acceptable treatment method for patients with edentulous spans of the jaws.

An essential step in the selection of appropriate implant sites is the presurgical radiographic examination. Radiographs reveal adjacent anatomic structures, such as maxillary sinus, mandibular canal and indicate the optimal direction of fixture insertion. A variety of radiographic techniques have been described to aid in presurgical implant site assessment. These include plain film radiography, conventional and computed tomography (CT).^{1,9,10,12,23,24}

Cross-sectional radiography is of interest to the dental radiologist and implantologist as it is a technique enabling coronal or sagittal views of the jaws to be made.¹ Transversal slicing system (TSS) is one such technique. It is a specialized radiographic technique using principles of narrow beam radiography and linear tomography which is integrated into dental panoramic machine to image cross-section of jaws and TMJ.^{2,7,24}

A tomogram consists of two types of information: (1) Information from the image layer that provides a relatively sharp image with higher frequency and (2) information from outside the image layer that is blurred and demonstrates with a low frequency.^{3,7,8,21,22,33} The information from the image layer is derived from the structures considered to be signals in the diagnostic task; information outside the image layer is considered to be noise.^{3,11,14,19,20}

With the current interest in implantology, there is an increased demand for cross-sectional imaging of the jaws. Cross-sectional views can be obtained by traditional linear, spiral and hypocycloidal conventional tomography or by using specialized computed tomography.^{4,16,18} However, the CT machines with specialized softwares are readily available in major cities; the amount of radiation dose to the patient, availability of trained staff and cost of the equipment are the major concerns.^{4,15,17,26,37}

On the other hand, rotational panoramic cross-sectional tomography is simple in operation, relatively inexpensive,

it is a part of panoramic system, has short exposure time and low radiation dose to the patient.^{5,27} The images obtained have high signals and can be used to identify anatomical landmarks and for the assessment of available bone for the placement of fixture.²⁸

This new approach of panoramic cross-sectional tomography will be widely used which will result in greatly reduced need for CT examination and a marked reduction in radiation exposure.³⁰⁻³²

This study is done to evaluate the technique of panoramic cross-sectional tomography, to test the image quality, to evaluate the accuracy of the imaging layer, to evaluate horizontal and vertical magnifications, to evaluate angular and three-dimensional distortion in objects of different shapes and size, to evaluate the details as seen in the images, to validate the evaluation of quality assurance and clinical efficacy of TSS system^{6,24,29,35} (Fig. 1).

MATERIALS AND METHODS

Twenty-five mandibles were utilized for the study. Out of these, five were used for linear dimensional accuracy measurements and 20 were used to study the details.

For determination of linear dimensional accuracy, four parameters were taken to study as follows:

1. *Determination of direction of slice:* An assembly for the determination of direction of slide consisted of a modified angle measurement scale which was prepared using a protractor to which a 6 × 6 mm metal plate was suspended to a plastic rod. A needle pointer was attached to the plastic rod which was corresponding to the long axis of the plate. With this assembly, it was possible to calculate the degree of rotation made to the plate. An edentulous mandible was taken and block of 2 × 2 cm buccal cortical plate was carefully removed by postal stamp method keeping the superior cortical bone and lower border of the mandible intact in such a way that it could be repositioned to its original position (Fig. 2).

The medullar portion of the bone was cleared. The assembly was placed on the mandible with the metal plate within the mandible between the buccal and lingual cortical plate and the angle meter outside and over the crest of the ridge as shown in the Figure 2. The assembly was kept in the TSS equipment in such a way that needle and the plate were in the area of image layer. A metal plate was placed in the center of the mandible and radiographs taken by turning the plate clockwise and



Fig. 1: Planmeca PM 2002 CC

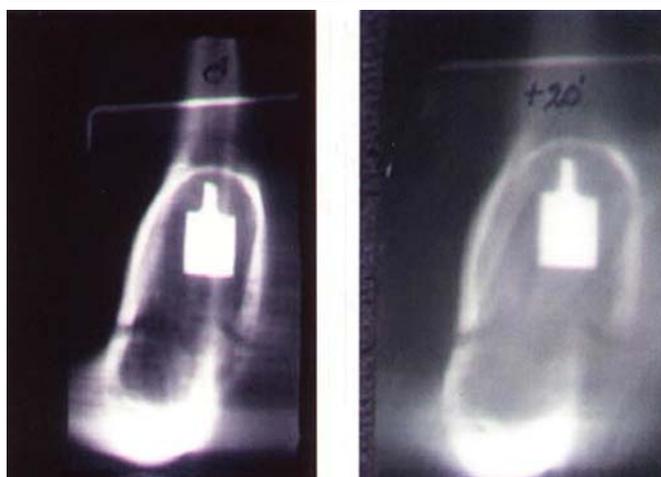


Fig. 2: Determination of direction of slice

anticlockwise at 0° , 5° , 15° and 20° . The clockwise direction was denoted as minus angulations and the anticlockwise was denoted as plus angulations. In such manner, nine readings were obtained from nine radiographs. The plate was then moved anteriorly first by 1 mm and then by 2 mm. This gave 18 more radiographs. Similarly from the center point, the plate was moved posteriorly by 1 and 2 mm and 18 radiographs were taken. In all, 45 radiographs were studied. The measured value on the radiographs was denoted as MV, this value was then divided by 1.45 (magnification factor) and the corrected value was obtained and denoted as CV. The actual value of the plate, which was 6/6 mm, was denoted as AV. The distortions of the resultant images were calculated in a single-blind study and exact direction of slice was thus determined as the angle with least distortion.

2. *Determination of horizontal and vertical magnification:* 0.5 mm diameter metal balls were used in preparing a grid. The metal balls were placed at a distance of 1 mm apart that were embedded in a acrylic sheet. The grid was prepared by placing three balls vertically and horizontally with care being taken that each ball being equidistance 1 mm apart in horizontal and vertical direction (Fig. 3).

This grid was attached to the same assembly which was used for the determination of direction of slice and whole of the assembly was transferred on to the mandible with the grid inside the cortical plates and angle meter over the crest. Radiographs of the grid were taken with an intervals of 0° , $+20^\circ$, $+15^\circ$, $+10^\circ$, $+5^\circ$, -5° , -10° , -15° , -20° . A total of nine radiographs were taken. Later the assembly was moved 2 mm anteriorly and 2 mm posteriorly with 1 mm intervals and nine radiographs were taken with change in 5° rotations at 1 mm intervals. The total movement of the grid was 4 mm, which is equal to the thickness of the slice. Magnification of ball in both horizontal and vertical direction was calculated and checked with the manufacturers claim. In all, five radiographs were taken in this manner.

3. *Determination of angular distortion:* A tunnel was prepared in two mandibles. One tunnel starts anterior to the area of slice on the buccal side passing through the center of slice and emerging from the lingual side posterior to the center of the slice. The other tunnel was made in the second mandible in the direction of the slice passing from the buccal side superiorly at the crestal level to the lingual side of the inferior cortex, but throughout being in the center of the slice (Fig. 4).

So, one was angulated in the anterior-posterior direction, while the 2nd was angulated in the buccolingual

direction. A plastic rod containing five metal balls of 2 mm dimension were placed at equidistance from each other. Two radiographs were taken, one each of the mandibles.

4. *Determination of three-dimensional distortion:* A cube was prepared with 20 gauge orthodontic wire of 6×6 mm, this cube was divided into two cubes by another wire, which divided the cube into one cube of 4 mm and another cube of 2 mm. The 4 mm cube was kept on the crest of the mandible which was adjusted in such a way that 4 mm cube coincided with the image layer and 2 mm part of cube was outside the image layer. Radiographs were taken with TSS apparatus and 3D distortion within the cubes were studied (Fig. 5).

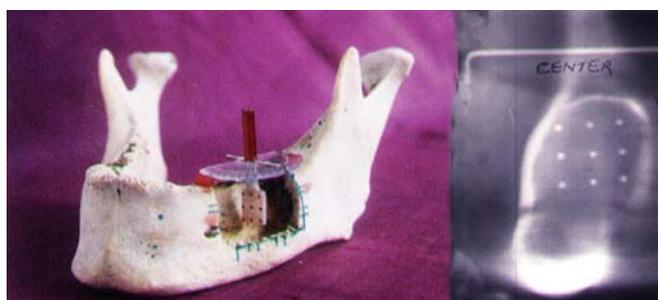


Fig. 3: Determination of horizontal and vertical magnification



Fig. 4: Determination of angular distortion

A pyramidal-shaped cube was prepared with 20 gauge wire where the base was of 10 × 10 mm and the apex had a measurement of 5 × 5 mm. Radiographs of this pyramidal cubes were taken with TSS apparatus keeping these on the crest of the mandible. The pyramidal cube was adjusted in such a way that the 10 mm side of the pyramidal cube was within the image layer and the 5 mm side of the pyramidal cube was kept distal to the image layer and radiographs were taken and 3D distortion of both the ends were studied.

A 4 × 4 mm diameter long metal cylinder was used to check the 3D distortion of cylinder by keeping the opening ends placed mesiodistally over the crest of the mandible, keeping the cylinder within the image layer.

Determination of Details

Twenty dry mandibles were selected to determine the details of the mandible in this study. The selection criteria of the mandible were that mandible should be edentulous behind the mental foremen, i.e. in the region of 2nd and 1st molar region.

On each mandible, four points were selected and marked by permanent marker (Fig. 6). 1st point—on the superior crest; 2nd point—on the inferior border of the mandible; 3rd point—on the middle of the buccal surface and the 4th point—on the middle of the lingual surface. Perpendicular lines were drawn connecting all the four points. Four metal balls of 2 mm diameter were glued to the points marked on the mandible, and the dry mandibles were placed in the TSS apparatus with the lower border of the mandible parallel to the floor and the perpendicular line with the four balls coinciding with the image layer and the area of interest was adjusted such that it was tangential to the mid-sagittal line.

Radiographs of the dry mandible were taken using TSS apparatus at two levels. Level 1 keeping the mandible at the base level of the TSS apparatus jig and the level 2 keeping the mandible to the level of bite block provided.

Radiographs of all the mandibles were exposed using program no. 61 (manual mode) of Planmeca PM 2002 CC. Exposure values were standardized for all the dry mandibles which was kept at 62 kvp, 4 mAs and 4.5 seconds. Total 40 sets of radiographs were made (20 radiographs of level 1 and 20 radiographs of level 2), same mandibles were utilized for levels 1 and 2.

Four balls which were glued to the mandibles, served as reference points for measurements on the radiograph. Five observers (three maxillofacial radiologist, one prosthodontist and one BDS doctor) were utilized for the tracings of the radiographs. Radiographic tracing was done on 36 micron thickness paper with a 0.5 mm lead pencil (Fig. 7).

Both inter and intraobserver’s variations were tabulated. The first readings given by the observer were taken for inter observers reliability readings. Then each observer was asked to give his or her measurements for five times at 24 hours interval. These measurements were taken for intraobserver reliability readings.

Twenty mandibles were utilized for the study to determine the details. The region of the slice was marked on the mandible with a marker pen. A lead ball was kept on

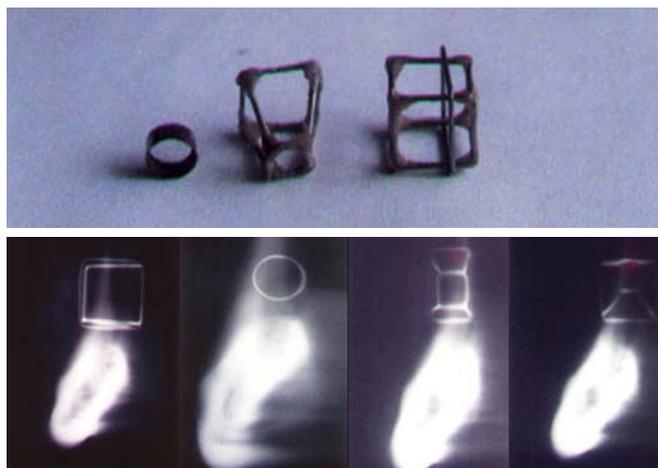


Fig. 5: Determination of three-dimensional distortion

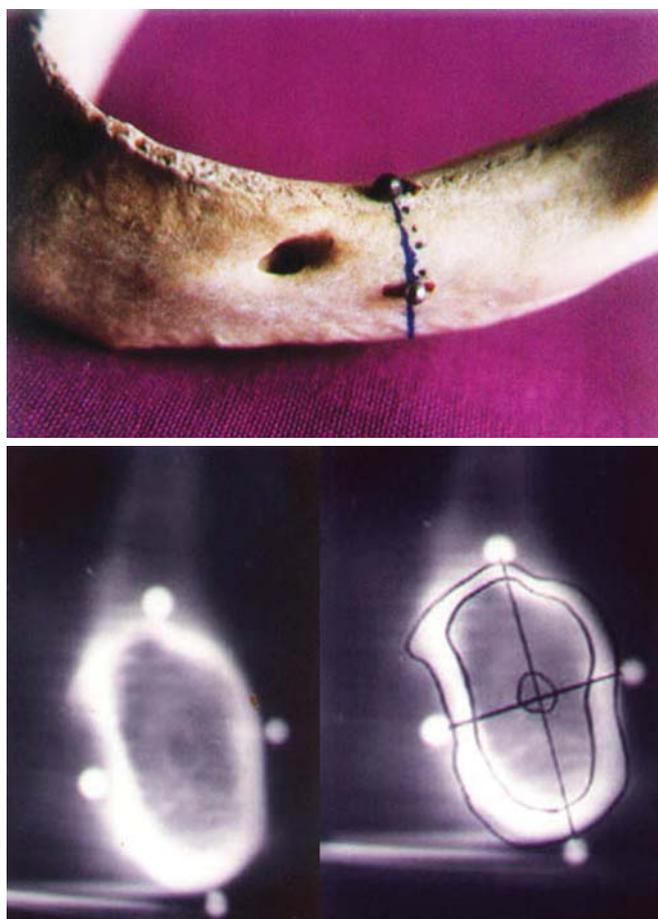


Fig. 6: Determination of details

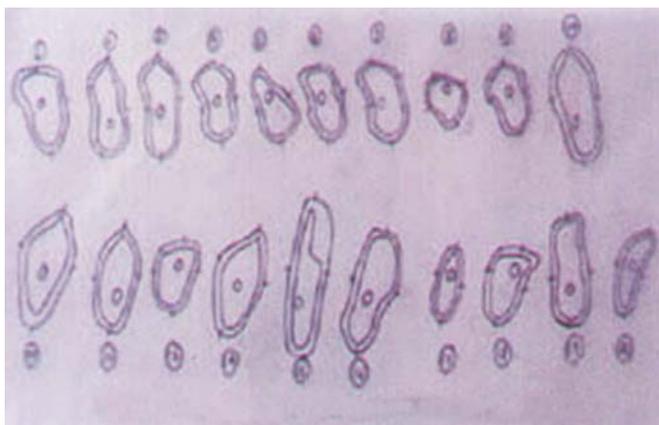


Fig. 7: Tracing of 20 mandibles

the superior crest and radiographs were taken. The manufacturers have provided a bite extension piece, which is adjusted in the groove provided in the equipment for positioning of the mandible. It is recommended by the manufacturer that the mandible can be positioned vertically in two different positions and these are either on the base of the jig or by using the extension bite piece, the mandible could be placed a little higher. Thus, the radiographs were taken at these two levels for all the 20 mandibles.

This meant that a total of 40 radiographs were taken. To check the details, nine different parameters were utilized at each level amounting to 18 parameters. These parameters were as follows:

1. Crests to canal (C to C)
2. Buccal to lingual (B to L)
3. Canal diameter (CD)
4. Total length (TL)
5. Superior cortical thickness (SC)
6. Inferior cortical thickness (IC)
7. Buccal cortical thickness (BC)
8. Lingual cortical thickness (LC)
9. Radiographic trabecular pattern (RTP)

All the measurements were done by tracing the cut section of the mandible produced on the radiograph by the TSS. Thus, the five observers for 20 mandibles at two different levels and five readings did $5 \times 20 \times 2 \times 5 = 1000$ tracings for intraobserver testing. This means each observer had traced 200 tracings respectively. Similarly for interobserver tracings, the five observers for 20 mandibles at two levels with one reading traced 200 tracings. This means each observer has traced 40 tracings respectively. In all, the five observers for inter-and intraobservations utilized 1200 tracings.

Tables 1 and 2 show the measurement values as MV, for all the different criteria, for all levels, for all the mandibles, for each observer. The measured value was then divided by 1.45, which is the magnification factor for TSS

as given by the manufacturer. This value is labeled as corrected value (CV) next to the measured value. Each of the mandibles was then sliced exactly in the region of the marking done on the mandible by the marker pen. This acted as a gold standard and represented the actual value (AV) and was labeled next to the corrected value for both inter and intraobservers reliability testing.

The reading for the radiographic trabecular pattern (RTP) was given in the form of scores, ranging from: (1) Very clear pattern, (2) clear pattern, (3) partially clear pattern, (4) not so clear pattern and (5) unclear pattern. After the mandible was sliced, the trabecular pattern was given as cores, which acted as gold standard (Fig. 8). These readings were labeled as RTP for the radiographic trabecular pattern and FTP for the factual trabecular pattern (Tables 1 and 2).

RESULTS

An *in vitro* study on dry mandibles was done to check the dimensional stability in the images produced by TSS.

The Determination of Direction of Slice

Findings

When the plate is in the center of the slice, the image is even both in the horizontal and vertical direction. As the

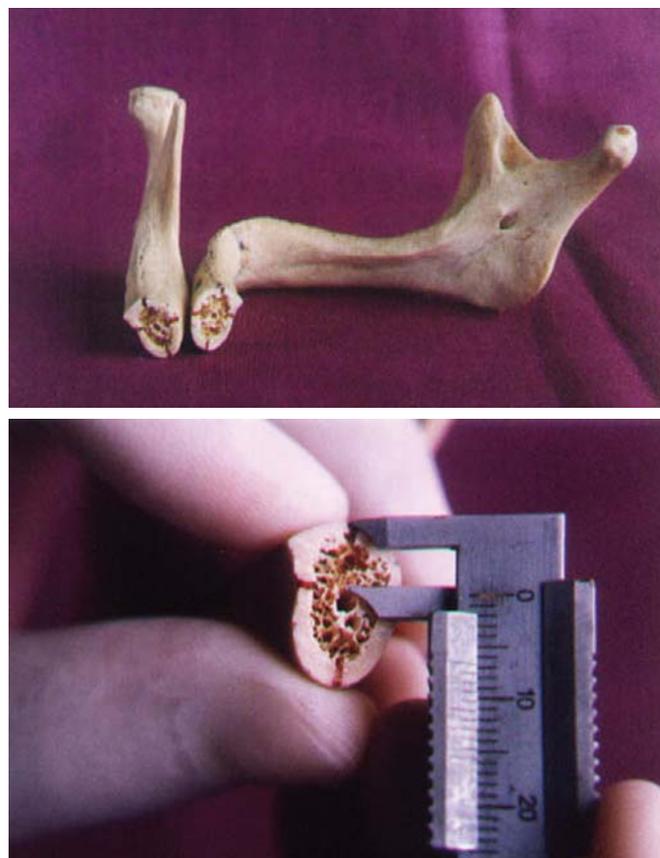


Fig. 8: Gold standard values taken after cutting the mandible

angle is increased from 5° to 20°, there is progressive distortion in the horizontal dimension. Nevertheless, even at 0°, the dimensions are differed by 0.49 mm, which is within the acceptable limit.

Determination of Horizontal and Vertical Magnification

Findings

At the center of the slice, the dimensions in both horizontal and vertical directions are equal but slightly smaller than the actual values. As we move anteriorly, the space between the balls in the horizontal direction is reduced suggestive of horizontal magnifications of the balls. Whereas vertically, the dimensions between the balls are smaller, suggestive of slight vertical magnification. The vertical magnification is less than the horizontal magnification. Conversely when the grid is moved posteriorly, the vertical magnification is more than the horizontal magnification. These

magnifications are linearly progressing as we move away from the center of the slice in both the anterior and the posterior direction. The results again confirm the principles of panoramic radiography.

Determination of Angular Distortion

Findings

In the anterioposterior direction, the ball in the center of the slice is nearly correctly imaged. But as the angle increases, there is progressive distortion. In the direction of the slice, the balls that are placed within the mandible show almost correct dimensions while those, which are out of the mandible, are progressively distorted. The results show that when objects are placed angularly in antero-posterior directions, there is a great amount of distortion on the other hand when the balls are placed in the center of the slice (or) the focal through. The distortion is present but well within acceptable limit. In the anterior-posterior direction, the ball

Table 1: Cross tabulation of RTP/FTP (Inter observers analysis)

RTP/FTP (Inter observer analysis)							
RTP	FTP	2	3	4	5	Row (Total)	Row (%)
1	–	4 (2%)	5 (2.5%)	–	–	9	4.5
2	–	51 (15.5%)	23 (11.5%)	4 (2%)	–	58	29.0
3	–	32 (16%)	46 (23%)	5 (2.5%)	–	83	83.0
4	–	16 (8%)	16 (8%)	16 (8%)	9 (4.5%)	42	42.0
5	–	7 (3.5%)	–	–	1 (0.5%)	8	8.0
Column (Total)	–	90	90	10	10	200	–
Column (%)	45	45	10	10	–	–	–

Chi-square—Pearson likelihood ratio

SPSS/PC + Value	DF	Significance
45.07121	12	0.00001
45.75776	12	0.00001

Minimum Expected frequency = 400; Cell with expected frequency = less than 5 to 20 (70%)

Table 2: Cross tabulation of RTP/FTP (Intra observers analysis)

RTP/FTP (Intra observer analysis)							
RTP	FTP	2	3	4	5	Row (Total)	Row (%)
1	–	–	2 (0.2%)	–	1 (0.1%)	3	0.3
2	–	160 (16%)	137 (13.7%)	8 (0.8%)	–	305	30.5
3	–	207 (20.7%)	255 (25.5%)	40 (4%)	19 (1.9%)	521	52.1
4	–	72 (7.2%)	46 (4.6%)	2 (0.2%)	27 (2.7%)	147	14.7
5	–	11 (1.1%)	6 (0.6%)	–	3 (0.3%)	20	2.0
Column (Total)	–	450	450	50	50	10000	–
Column (%)	–	45	45	5	5	100	–

Chi-square—Pearson likelihood ratio

SPSS/PC + Value	DF	Significance
117.90771	15	0
113.60268	15	0

Minimum expected frequency = 150; Cell with expected frequency = less than 5 to 10 of 24 (41.7%)

placed most anteriorly and buccally was placed outside the focal through and was too distorted to record a good image.

Determination of Three-dimensional Distortion

Findings

From the results, it can be seen that there is less distortion in the circular object, whereas the angled cubical objects showed extreme distortion as they went away from the focal through. The distortion almost obliterated the regular shape of the objects. This effect has tremendous importance in visualization and detection of the trabecular pattern of bone, which may become unclear due to three-dimensional distortions.

Determination of Details

To evaluate interobserver and intraobserver reliability, the statistical method analysis of variance was utilized. In this analysis, factorial experiment was utilized. For interobserver reliability, two factors were utilized namely factor 1 for observers, factor 2 for levels. Thus, it was a two factorial analysis. For intraobserver reliability, three factors were utilized, namely factor 1 for observers, factor 2 for time, factor 3 for levels. Thus, it was a three factorial analysis.

The tables are divided into sets for interactions of each parameter. For example, set 1 denotes the interaction between the observer and level for parameter C to C. Set 2 denotes interactions between observer, level for parameter B to L and so on for each of the parameters. Similar sets are utilized for intraobserver using three factors.

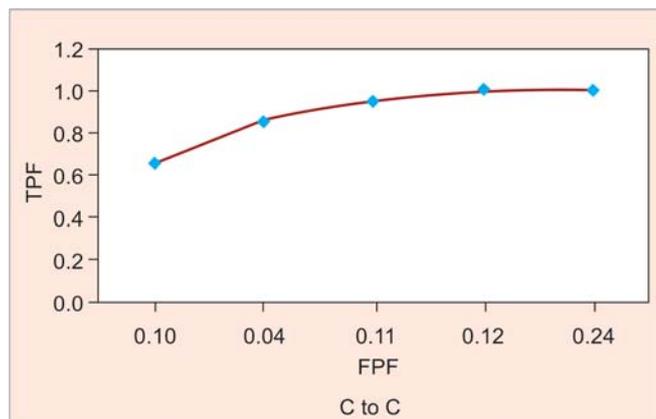
In these tables, under the source of variation, a treatment denotes the mean of the five observer’s observation at two levels. Factor 1 (F1) denotes observer’s observation; factor 2 (F2) denotes levels. The values F1 × F2 denote the interaction for significance between the observer’s observations at two levels.

The source of variation control vs treatment (con vs treatment), where control means actual value and treatments means the observer’s observation, denotes the significance of interaction between actual and corrected values. This analysis is done at a standard degree of freedom. The F ratio is then calculated using the sum of squares and mean of squares. The F ratios were then checked utilizing the F-distribution tables at both 1% as well as 5% levels/points; utilizing the statistician’s biometric tables.

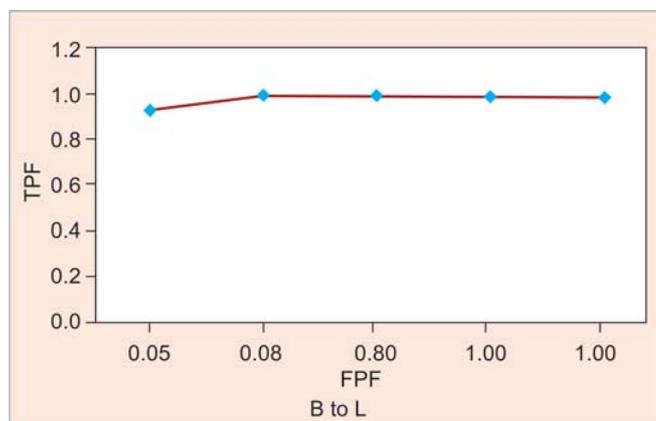
The consolidated experimental mean values and the actual mean values, which were obtained by the factorial analysis for each variable, like crest to canal (C to C) (Graph 1), buccal to lingual (B to L) (Graph 2). Total Length (TL) (Graph 4). Superior cortical thickness (SC) (Graph 5). Inferior cortical thickness (Graph 6). Buccal cortical thickness (Graph 7). From the tables it can be seen

that there is high percentage of accuracy for almost all the different parameters. The accuracy percentage ranges from 94.7% for canal diameter (CD) (Graph 3) to 101.9% for lingual cortex (LC) (Graph 8). This shows that the different parameters may be undervaluated by 6% or overevaluated by 1%. These values are well within the acceptable limits as 6% amounts to 0.15 mm which is insignificant.

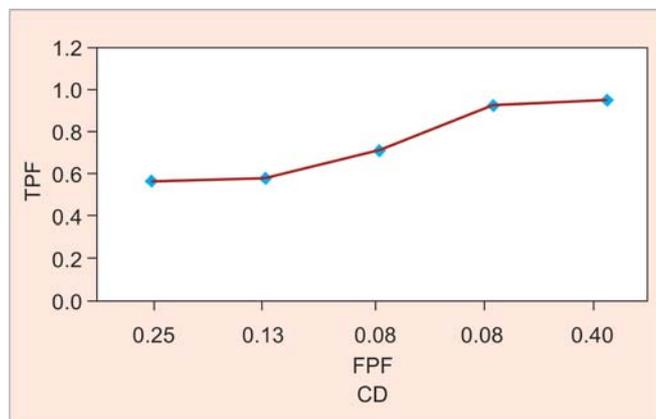
In the intraobserver factorial analysis, it can be seen that the range of accuracy for most of the parameters is well within the acceptable limits of 95 to 100%. Major



Graph 1: Crests to canal (C to C)



Graph 2: Buccal to lingual (B to L)



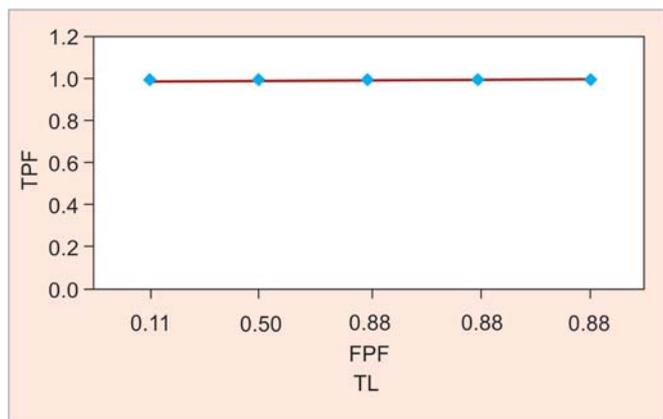
Graph 3: Canal diameter (CD)

variations were noted for buccal cortical thickness and the inferior cortical thickness as well as to some extent in the canal diameter. Even that difference when converted into millimeter amounts to 0.45 mm which is insignificant.

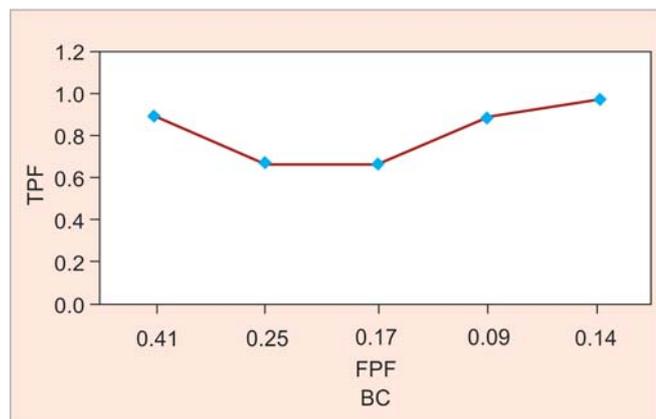
The parameter's radiographic trabecular pattern was evaluated by the SPSS software 8079 cells with dimensions for cross tabulation. The horizontal axes are the FTP and the vertical axes are the RTP (Graph 9). No. 1 denotes very clear pattern, no. 2 denotes clear pattern,

no. 3 denotes partially clear patterns, no. 4 denotes not so clear pattern and no. 5 denotes unclear pattern. Using the Chi-square test and the Pearson likelihood ratio, it can be seen that the readings are significant even at 0.00001 level. Similar readings are seen for intraobserver, where the significance differences are at 0.00000 levels (Tables 1 and 2).

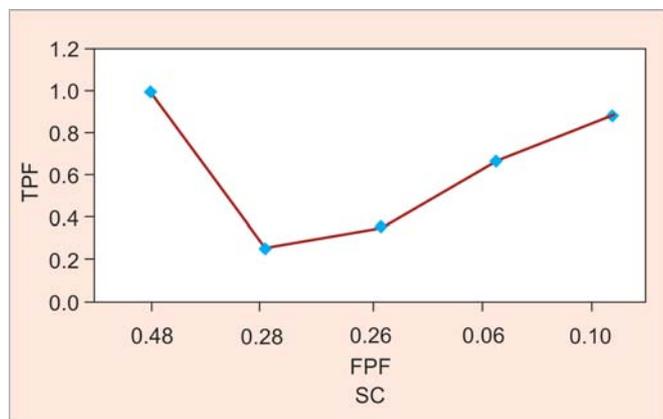
This shows that there is wide variation both in inter- and intraobservation readings. Thus the evaluation of the trabecular pattern in the TSS appears to be unreliable.



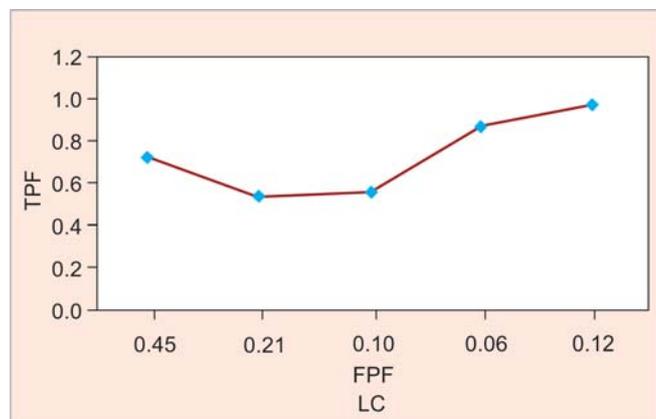
Graph 4: Total length



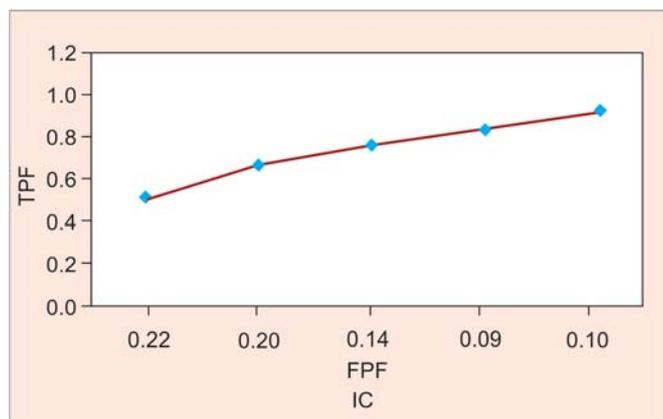
Graph 7: Buccal cortical thickness (BC)



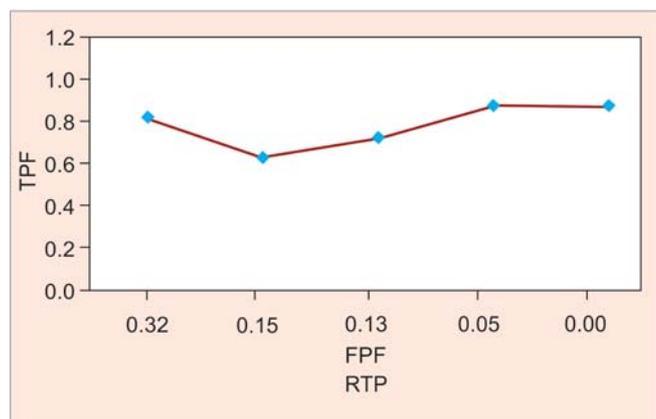
Graph 5: Superior cortical thickness (SC)



Graph 8: Lingual cortical thickness (LC)



Graph 6: Inferior cortical thickness (IC)



Graph 9: Radiographic trabecular pattern (RTP)

The receiver operating characteristics (ROC) and the area under the ROC curves measure the accuracy of any imaging modality, especially in radiography. ROC curves are plotted between sensitivity and specificity of an imaging system. The sensitivity and specificity of each parameter for both inter- and intraobserver were calculated. These were done at five different confidence levels for each parameter. First the true positive, the false positive, the false negative and true negative results were calculated. From these sensitivity and specificity were calculated using the standard formula.

ROC curves were then plotted for each parameters for both inter- and intraobserver reliability. From the graphs, it can be noted that if we take the cut-off point as 0.5 at the true positive fraction (TPF), in most of the parameters, the results are above the curve.

Variation can be seen in canal diameter (CD) (Graph 3) Superior conical thickness (SC) (Graph 5) and the lingual cortical thickness (LC) (Graph 8). Minor difference can be noted in the buccal cortical thickness (BC) (Graph 7) in the ROC curves of interobserver readings. Only in the radiographic trabecular pattern, we find that the major part of the curve is at 0.5 levels suggestive of highly randomized reading.

In the ROC curves of the intraobserver, CD (Graph 3), SC (Graph 5) and LC (Graph 8) thickness appear closer to the randomized readings.

To find the spatial distribution of the points under the ROC curves, graphs using the random distribution points of the Microsoft Excel software were utilized at various confidence levels. For all the nine parameters, it can be seen that even at confidence level 1 where the freedom of variation is minimal most of the points are at 0.5 level or above, suggestive high level of accuracy of measurements of all the parameters.

As the confidence level is decreased, the points for the entire parameters shift to one in both inter- and intraobserver readings.

It can be noted that CD inferior cortical thickness IC and LC are the three variables which are consistently have at both the levels between all observers, have randomized readings suggesting that there is lot of variation in the radiographic appearance of these parameters.

The LC was overscored suggestive that it is horizontally magnified. To a lesser extent, there is a vertical magnification of the inferior cortex (IC). As far as the canal diameter is concerned, there was under scoring which suggests that there is a slight amount of distortion or overlapping of the canal dimensions.

DISCUSSION

Most of the manufacturers of panoramic imaging systems are now marketing some type of cross-sectional capabilities for those units. This capability is of interest to dental surgeon who is practicing implant dentistry. Irrespective of whether it is surgical stage, diagnostic or treatment phase, multitask radiography finds a place at all stages. New imaging systems may be thoroughly tested by these manufacturers.^{36,42,43} But it is essential that the users of this equipment, i.e. the members of dental faculty, evaluates the efficiency and efficacy of all these machines either individually or in comparative terms.^{23,24,34}

The TSS of the machines used in the present study was able to produce images that were accurate, consistent and sufficient to assess the dimensional accuracy of the different radiologic parameters.^{45,51} The *in vitro* part of the study was restricted to the posterior part of the mandible for two reasons: (1) It is a good representative site having enough parameters to measure and (2) because most of the interest in implant radiology is concentrated in this area. Potter et al^{13,39,41,44} in their study had also chosen the posterior part of the mandible in their study.

Potter et al^{13,38} in their study found that both the machines that they evaluated, the patient can be easily guided to the most proper position for a good transversal slice. Both the elaborate positioning parameters, which are to check, can create difficulty in patient positioning with consequently loss in the image quality.⁴⁰

An *in vitro* study was conducted to evaluate dimensional accuracy and details of the panoramic images. Twenty-five dry mandibles were utilized for this study, as the focus of attention was maintained in the posterior part of the mandible. The posterior part of the mandible gives an opportunity to study adequate number of parameters for proper evaluation. Of these 25 mandibles, five mandibles were used for linear dimensional accuracy measurements whereas the remaining 20 were used for studying details and also to find the inter- and intraobserver reliability.

The quality assurance test in the five mandibles was to find the accuracy of the slice, horizontal and vertical magnification, angular distortion and three-dimensional distortions. Specialized test objects in the form of a metal plate, a grid made up of metal balls, a tube containing metal balls, cylinder, cube and a tapering cube were utilized. Stabilizing and adjustment apparatus was designed to carry out the various quality assurance tests.^{45-47,50}

Metal plate made up of nickel was used to determine the direction of slice. The plate could be moved forward and backward and rotated clockwise and anticlockwise. A modified scale was used which could measure the rotational movements. TSS radiographs were taken by

rotating clockwise and anticlockwise direction in increments of 5° moving the assembly forward and backward at 1 mm increment carried out similar procedures.

Horizontal and vertical dimensions of the plate in each of the vertical dimensions of the plate in each of the radiograph was measured, tabulated and compared with the actual values. Results showed that in the direction of the slice and at the position of the slice, the measurements from +5° to -5° were within acceptable limits.

In another mandible, a grid using nine metal balls was prepared and placed in an assembly, which could be moved forward and backward. The assembly was placed at the region of the slice and radiographs were taken. Subsequently, radiographs were taken moving the assembly forward and backward at 1 mm increments. In the region of slice, the vertical and horizontal magnification was equal. Magnification and consequent distortion were seen both in the anterior and posterior direction. The degree of magnification both in the horizontal and the vertical direction confirmed the principles of panoramic radiography.^{48,49}

In another mandible, a tunnel was created in anterior-posterior direction passing from buccal aspect to the lingual aspect. A tube containing metal balls placed at regular intervals was inserted and radiographed. In another mandible, the tunnel passed in the direction of the slice from the buccal to the lingual aspect. The results showed a magnification of the balls confirming to the principles of panoramic radiography^{52,53} but showed no distortion in the angular measurements.

Over another mandible, all the three different three-dimensional objects were placed one after another and radiographed. The objects showed minimal distortion in the area of slice but showed progressive distortion as the object went away from the center of the slice. There was also slight superior displacement of the part of the object which was placed outside the area of the slice. The part of the object, which was further away from the slice, in fact showed the tomographic blurring and was not traceable.

Twenty dry mandibles were utilized to determine the details. Nine parameters were used and they were crest to canal, buccal to lingual, canal diameter, total length, superior cortical thickness, inferior cortical thickness, buccal cortical thickness, lingual cortical thickness and radiographic trabecular pattern. Cross-sectional panoramic radiographs were taken of all the 20 mandibles. Five observers were utilized for inter- and intraobservers reliability testing. The observers were asked to trace the outline of the image and give there measured values for all the parameters. The first tracings were used for interobserver testing. Subsequently, each observer was asked to do similar tracings at 24 hours

interval for all the 20 mandibles at both the levels. Measurements were taken and recorded. The measured value from the tracings was then divided by magnification factor of 1.45 to get the corrected values. Each mandible was then cut in the area of the slice and the actual values were taken by measuring from vernier calipers. The visibility of the trabecular pattern was estimated in the form of scores on a 5 point scale, ranging from 1—very clear pattern, 2—clear pattern, 3—partially clear pattern, 4—not so clear pattern and 5—unclear pattern. The results of both inter- and intra- observers when compared with gold standards, differed marginally by 5% which was well within acceptable limits.

Validity of the results was done by analysis of variance using two factorial for interobserver and three factorial for intraobserver testing. Thus, the result suggests that in comparison to the gold standard, there is no statistically difference with the measured values. Sensitivity and specificity of the measurements was calculated at different confidence levels and plotted as ROC curves. Using spatial distribution further highlighted the area under the curve.

The results show a high degree of accuracy in the measured dimensions and the visibility of different parameters. As most of the readings were above 0.5, which showed high degree of confidence in the observers' in both measuring and identifying the parameters. Some degree of randomness was found in lingual cortical thickness, inferior cortical thickness and the canal diameter. The visibility of the lingual cortex was most probably effected by the over lapping shadows of the blurred images of the posterior part of the mandible. The inferior cortical thickness discrepancy aroused due to positional defect and the slope of the mandible. The canal diameter was not seen properly due to the thin cortex and the path of the canal. In any case, the discrepancy was not in the interobserver but in the intra-observer's readings. The intraobserver discrepancy was due to fatigue, as each observer has to do 40 tracings per day. Second, the five observers comprised of three radiologists and two nonradiologists. There was great discrepancy in the readings given by nonradiologists which offset the mean values. Third, there was lack of training for interpretation of the observers. Nevertheless, 99% of the readings were in the clinically acceptable limits.

A small *in vivo* testing also did validation of the results of the *in vivo* study. Few patients who needed atleast one tooth to be extracted were selected. TSS was taken. Centering the tooth meant for extraction. The teeth were extracted, cleaned and sterilized and the total length from cusp to tip of the root and buccolingual width was measured actually on the tooth and compared with the measurements

on the TSS images. The discrepancy was within the $\pm 5\%$, which was similar to the *in vitro* study.^{33,54,55}

CONCLUSION

1. TSS radiography shows images which are dimensionally accurate to $\pm 5\%$ accuracy.
2. The patient positioning apparatus adequately positions the patient for standard radiographic images.
3. The TSS uses 1/4 the time of exposure for each slice, as compared to the normal panoramic radiograph.
4. An error in-patient positioning up to 5° clockwise and anticlockwise in the horizontal plane does not distort the images.
5. The horizontal and vertical magnifications are equal in the region of the slice and are progressively distorted as one goes further away from the area of the slice.
6. Angular distortions are not very apparent in the region of slice.
7. Three-dimensional objects are distorted progressively as they are placed away from the slice.
8. Magnification, angular distortion and the shape and size changes are as per the principles of panoramic radiography as applied to TSS.
9. Details with respect to visibility and linear measurement can be adequately done on the TSS.
10. There is good reliability in both inter- and intra-observers' measurements.
11. Shorter time frame leads to slight unreliable readings from the observers, but they are still within acceptable limits.
12. Analysis of variance shows excellent results at both 1 and 5% levels/points.
13. Adequate radiographic interpretation training for the tracings is necessary, especially for nonradiologists.
14. TSS gives reliable results both with and without use of an extension bite piece, i.e. at both the levels.
15. Trabecular pattern interpretation on the TSS appears to be randomized and may be clinically unreliable.
16. Care should be taken while evaluating the inferior cortex. Good viewing conditions, high magnification and a well-processed radiograph are needed to observe the sharper image within the overlapping zone of the inferior cortex.
17. Care should be taken in visualization of the cortices of the mandibular canal as well as their dimensions. These may be unclear on the radiographs.
18. Use of metal balls, objects and plates are excellent method to study the quality assurance.
19. Patient should be positioned such that the alveolar ridge should be perpendicular to the direction of the beam.
20. ROC curves are the recommended tool in radiography for validation of radiographic interpretive results.
21. Dimensional accuracy of the *in vitro* study was confirmed in the *in vivo* study.
22. Extensive *in vivo* study should be the next step in the evaluation of the TSS.

The easy availability, use of routine equipment, the low cost and low radiation dose and the recommendation of AAOMR for cross-sectional radiography make the TSS the most preferred modality for this type of radiography.

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