

The Measurement of X-Ray Beam Size from Dental Panoramic Radiography Equipment

J R Holroyd

ABSTRACT

Dental panoramic X-ray equipment provides a challenge for the accurate measurement of dose area product (DAP) values, which are utilised to help ensure radiation doses to patients are kept as low as reasonably practicable.

This report describes a quick and accurate automated method using digitised images for the measurement of the dimensions of panoramic X-ray beams. The accuracy of the method is assessed by comparing its results against those obtained using a transmission densitometer and micrometer to precisely measure the optical density profile across radiographic images of panoramic X-ray beams. The method is also compared to two established alternative methods: using a ruler alone and using a ruler in combination with a light box and magnifying glass.

Both the digitised images method (average error of 7%) and the use of a ruler in combination with a light box method (average error of 6%) were found to show good agreement with the densitometer method. Comparing the ruler-only method to the densitometer method showed that the ruler method underestimates the beam width by on average 29%, but that this method could be accurately used for measuring the beam height.

Digitised images can be used to measure panoramic beam profiles as accurately as using a transmission densitometer, and with significantly improved speed compared to both this method and use of a ruler with a light box and magnifying glass. The use of a ruler alone is neither accurate nor consistent and should not be used to make these measurements.

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1 INTRODUCTION

The Dental X-ray Protection Service (DXPS) of the Health Protection Agency (HPA) provides an X-ray equipment performance testing service to the dental community (Hewitt, 1984). The service employs 'DXPS test packs' that are used to remotely assess the equipment performance of intra-oral and panoramic equipment.

A key component of this testing is to measure the radiation dose delivered to the patient. National reference doses (NRDs) have been established for panoramic radiography using the quantities, dose area product (DAP) (Institute of Physics and Engineering in Medicine [IPEM], 2005) and dose width product (DWP) (Hart, Hillier and Wall, 2007). DWP is the product of the radiation dose per exposure cycle and the width of the X-ray beam profile and is usually expressed in the units of mGy mm. DAP is then the product of DWP and the height of the X-ray beam, and is usually expressed in the units of mGy cm².

The DXPS panoramic assessment method requires a radiographic film (Kodak SR; Kodak, Hemel Hempstead, England) to be exposed at the cassette carriage (or for direct digital equipment, at the digital receptor) position for a complete radiographic cycle during a standard adult panoramic exposure. The image captured on the processed film can then be used to derive the dimensions of the X-ray beam at that position. The radiation dose at the same position is measured separately using the DXPS test pack. The dose area product can then be calculated and compared to the national reference dose to check that the equipment is capable of restricting patient doses to below the NRD providing proper exposure techniques are used. The measurement of the beam width is not a straightforward task as the radiographic image of the X-ray beam at the position of measurement is not sharply defined. In addition, different models of panoramic equipment have significantly different beam sizes and profiles. As typical measured beam widths are between 2 mm and 7 mm this measurement is critically important in accurately calculating the DAP. A method that is both accurate and reproducible is required. This true beam width is often not provided by manufacturers of panoramic radiography equipment and when it is provided, the method used to obtain the measurement is not supplied.

A number of methods have previously been proposed to measure panoramic beam profiles with varying accuracies. One report indicated that using a ruler on an exposed film gave a 20% overestimate of the beam width compared to measurement using an optical density beam profile (Isoardi and Ropolo, 2003). Alternative methods involve the use of in-beam ionisation chambers and DAP meters, to directly measure the dose area product, (Williams and Montgomery, 2000; Tierris, Yakoumakis, Bramis and Georgiou, 2004) which have been shown to provide accurate measurements. However, these methods require that the measurements are carried out onsite using specialist equipment.

This paper presents an automated method utilising digitised beam images which is both quick and easy to operate and has only a small associated cost. A similar method utilising digitised images has been shown to agree within 8% on measurements of dose width product compared to the direct measurement of dose using an ionisation chamber

(Doyle, Martin and Robertson, 2006) indicating that this may be a suitable methodology for the measurement of panoramic X-ray beam profiles.

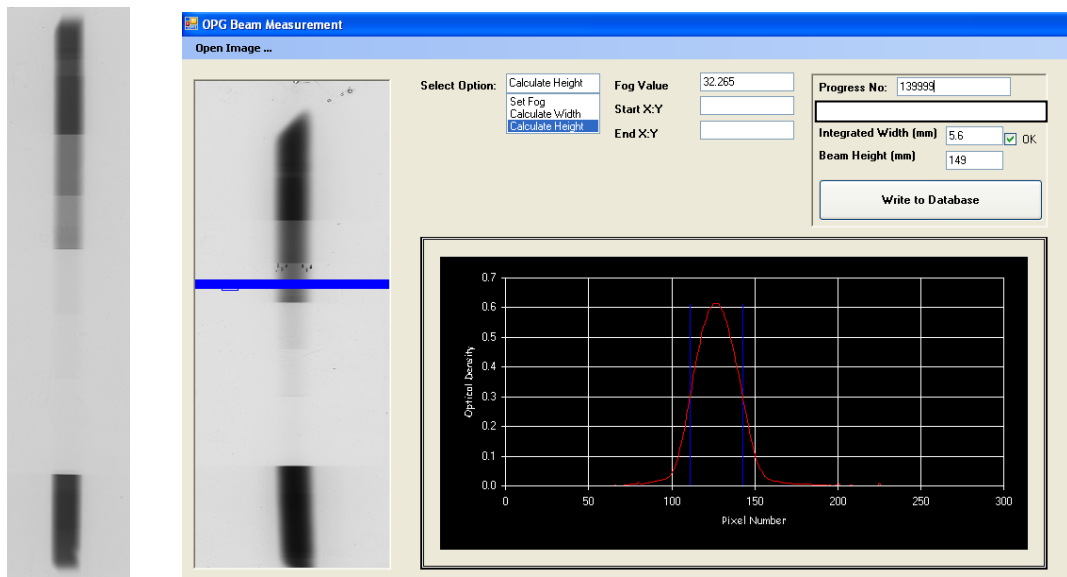
2 METHOD

2.1 Hardware and Software

A flat-bed scanner has been obtained (Epson Perfection V700 Photo; Epson (UK) Ltd, Hemel Hempstead, England) which is capable of the transmission scanning of film transparencies with an optical density range of up to 4D. Following darkroom processing, the test pack films bearing the image of the X-ray beam are scanned using the scanner's default software package (Epson Scan; Epson (UK) Ltd, Hemel Hempstead, England) and the resultant images are saved as 8-bit greyscale uncompressed tagged image file format (tiff) files.

A custom software application has been designed using Microsoft Visual Basic 2005 (Microsoft; Redmond, USA). The image of a film is loaded into the program, the greyscale values are read and converted to optical densities using a fourth order polynomial relationship which was established for this type of X-ray film. The beam width and height measurements can then be automatically computed, as illustrated in Figure 1.

Figure 1 A typical beam film and the beam measurement software user interface



2.2 Measurement method

The radiation dose delivered to the Kodak SR film can vary by a factor of ten for different models of panoramic equipment. Due to this it is important that the X-ray beam incident on the film is suitably filtered to ensure that the developed film is neither saturated nor underexposed.

The DXPS test pack includes a number of copper filters of varying thicknesses. This ensures that at least a portion of the beam profile will be clearly visible on the film for the wide range of radiation exposures that the film may receive. For consistency, the beam width is always measured at the position on the film where the peak optical density is closest to 1. This ensures that the full beam profile is always used to calculate the beam width, without the peak of the profile saturating the film or the film scanner.

To calculate the beam width, the area under the optical density profile is calculated and this is divided by the peak optical density to give the width that would be expected of a square profile with height equivalent to the peak optical density. Previous reports have used a full width at half maximum (FWHM) measurement of the dose profile (Isoardi and Ropolo, 2003; Doyle, Martin and Robertson, 2006) to determine the dose, however this has been shown to underestimate the dose due to the shape of the dose profile (Williams and Montgomery, 2000). Ten profiles are obtained across the filter area selected and averaged to reduce inconsistencies associated with inhomogeneity of the film. The beam height is a simple measurement of the length of the beam image. The beam height is considerably greater than the width and typically has well defined edges, therefore there is less chance of error on the measurement and any error has significantly less influence on the dose area product calculation.

2.3 Evaluation

Twenty films were selected at random from a large selection of beam profile films. The films were sorted into an order whereby similar beam profiles were not adjacent to each other to reduce possible bias.

Three established alternative methods were also evaluated to assess their relative ability to measure panoramic beam profiles: using a ruler (British Institute of Radiology [BIR], 2001), using a ruler in combination with a light box and magnifying glass and using a scanning densitometer (Isoardi and Ropolo, 2003). All the results were collected using a standard data collection form and once all the measurements had been made the results were collated and analysed.

2.3.1 Using a ruler

Four persons with experience of assessing panoramic equipment were selected to each independently measure the beam width and height of the test films using only a ruler.

The reproducibility of using a ruler to measure the width of the beam profile was also assessed. Two weeks after first measuring the films, two members of the department were asked to repeat the measurements of the beam widths which were then compared

to their original measurements. The beam height measurements were not repeated as there was considered to be far less subjectivity to this measurement.

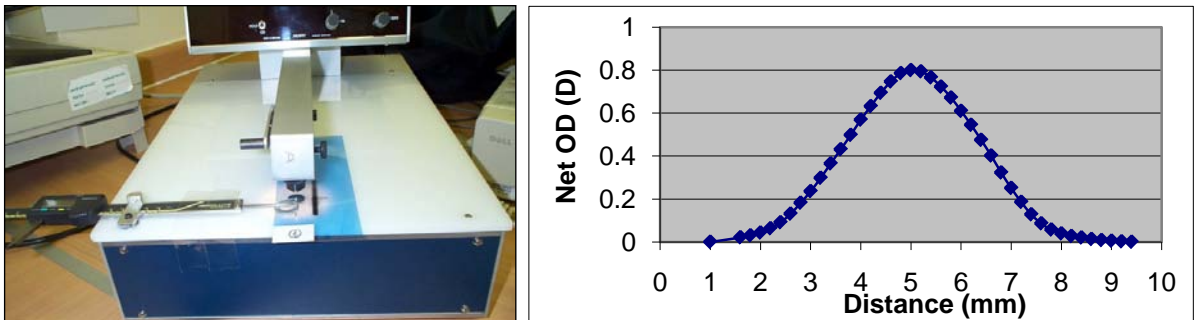
2.3.2 Using a ruler, light box and magnifying glass

A different person measured the beam films using a ruler, but with the addition of a magnifying glass and light box to assist with the measurements.

2.3.3 Using a transmission densitometer

Another person measured the width of the beams by manually obtaining an optical density profile using a micrometer and a desktop transmission densitometer (Parry DT1505; Alrad Instruments Ltd, Newbury, England) with a light source aperture of 0.2 mm. This method involved positioning the film on the densitometer and making measurements of optical density as the film was gradually moved across the aperture in increments of 0.2 mm. The resulting optical density profile could then be used to accurately calculate the beam width using the same measurement method described above which was used with the digitised images.

Figure 2 Transmission densitometer setup with a typical beam profile



3 RESULTS

The results of the measurements of the beam widths and heights of the 20 films, by all four members of staff using only a ruler, are presented in Figures 3 and 4 below.

Figure 3 Mean and range of beam width measurements made using a ruler.

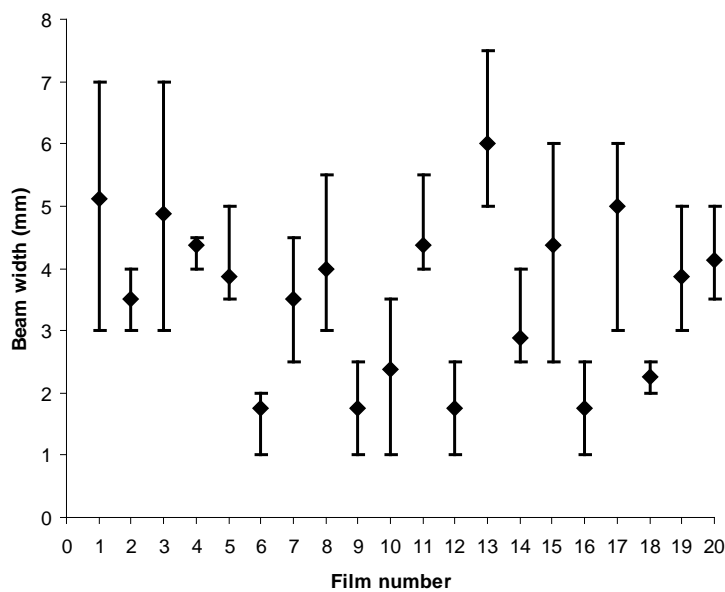
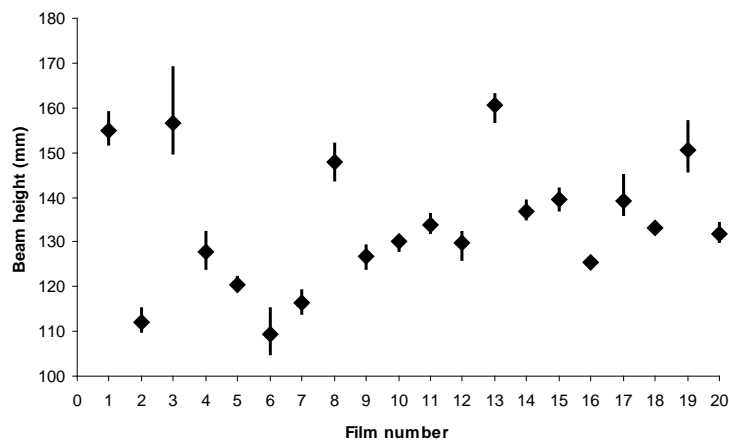


Figure 4 Mean and range of beam height measurements made using a ruler.



The results of the repeat measurements of beam width, made two weeks after the initial measurements, are shown in Table 1. It is apparent that the two members of staff produced significantly different results from reading the same films, and with a differing degree of consistency between their two individual reading sessions.

TABLE 1 Reproducibility of the ruler method when measuring beam width (measurements in mm)

Film Number	Reader 3			Reader 4		
	1 st Reading	2 nd Reading	Difference (% , rounded)	1 st Reading	2 nd Reading	Difference (% , rounded)
1	4	4.5	13	6.5	6.5	0
2	3	3.5	17	4	4	0
3	4	4	0	7	6.5	-7
4	4	4.5	13	4.5	5	11
5	3.5	5	43	5	5	0
6	2	3	50	2	2	0
7	3.5	4.5	29	4.5	4.5	0
8	3	3.5	17	4.5	4.5	0
9	2	3.5	75	2.5	2.5	0
10	3	4	33	3.5	3	-14
11	4	5.5	38	5.5	5.5	0
12	2	3	50	2.5	2	-20
13	5	6.5	30	7.5	7.5	0
14	2.5	4.5	80	4	4	0
15	3	4	33	6	4.5	-25
16	2	2.5	25	2.5	2.5	0
17	3	3.5	17	6	5	-17
18	2.5	3	20	2.5	2.5	0
19	3.5	3.5	0	5	4	-20
20	4	4	0	5	5	0

Table 2 lists the results of the beam width measurements made using the remaining three methods, while Table 3 lists the results of the beam height measurements made using the ruler and light box method and the digitised image method.

TABLE 2 Beam width measurements (in mm) using a ruler and light box, densitometer or digitised image. The digitised images were acquired using a scan resolution of 150 dpi.

Film number	Ruler and light box	Densitometer	Digitised image
1	6.0	6.1	6.2
2	4.5	4.6	4.9
3	6.5	6.2	6.3
4	5.0	5.3	5.6
5	5.5	5.4	5.8
6	2.5	2.8	3.0
7	5.0	4.7	5.0
8	5.0	5.0	5.5
9	3.0	2.8	3.0
10	4.0	3.7	4.1
11	5.5	5.9	6.4
12	3.0	3.2	3.4
13	8.0	7.7	8.0
14	4.5	4.4	4.8
15	5.0	5.8	5.8
16	3.5	3.2	3.4
17	6.0	6.2	6.7
18	3.0	3.1	3.3
19	5.0	4.8	5.1
20	5.5	5.9	6.1

TABLE 3 Beam height measurements (in mm) using both a ruler and light box and a digitised image

Film number	Ruler and light box	Digitised Image
1	155	155
2	114	113
3	156	155
4	129	129
5	120	119
6	106	106
7	117	118
8	150	148
9	127	126
10	131	131
11	134	134
12	132	131
13	162	162
14	138	138
15	140	140
16	126	125
17	140	140
18	133	132
19	152	150
20	134	132

4 DISCUSSION

The beam width results obtained using the densitometer method were taken to be the “true” result as this method has been shown to be an accurate means for making this measurement (Isoardi and Ropolo, 2003). In the discussion which follows, the measurement results obtained using the alternative methods are, therefore, presented as a percentage deviation compared to the value obtained using the densitometer. For the beam height measurements, the digitised image method was considered to be the accurate method as the densitometer was not used for this assessment due to the labour intensive nature of the method and the reasonable expectation that this measurement can be made accurately using simpler methods.

4.1 Beam width measurements

4.1.1 Comparison of the ruler method to the densitometer method

TABLE 4 Percentage error on measuring beam width using a ruler

Film Number	Reader 1	Reader 2	Reader 3	Reader 4	Average	Min	Max
1	-50	16	-34	7	-15	-50	16
2	-34	-12	-34	-12	-23	-34	-12
3	-51	-11	-35	14	-21	-51	14
4	-16	-16	-25	-16	-18	-25	-16
5	-35	-35	-35	-7	-28	-35	-7
6	-29	-64	-29	-29	-38	-64	-29
7	-47	-26	-26	-4	-26	-47	-4
8	-40	10	-40	-10	-20	-40	10
9	-46	-64	-29	-11	-38	-64	-11
10	-47	-73	-20	-7	-37	-73	-7
11	-33	-33	-33	-8	-26	-33	-8
12	-52	-68	-37	-21	-44	-68	-21
13	-23	-29	-35	-3	-23	-35	-3
14	-43	-43	-43	-9	-35	-43	-9
15	-56	6	-47	6	-23	-56	6
16	-53	-69	-38	-22	-45	-69	-22
17	-18	-2	-51	-2	-18	-51	-2
18	-34	-34	-18	-18	-26	-34	-18
19	-37	-16	-26	5	-18	-37	5
20	-32	-40	-32	-15	-29	-40	-15
RMSE*	40	40	34	13	29	50	13
Standard Deviation	12	28	8	11	9	14	12

* RMSE is the root mean squared error

The values measured with a ruler underestimate the beam width by an average of 29%. However, there is a large variation between one reader (Reader 4) and the other three. Reader 1, Reader 2 and Reader 3 underestimate the beam width by an average of 40%, 40% and 34% respectively whereas Reader 4 underestimates the beam width by an average of 13%. For five films (films 1, 3, 8, 15 and 19) one or more readers measured the beam width to be greater than the measurement made using the densitometer method. These five films also show a wide range of measurements between the four members of staff (for film 1 the range of measurements is 4 mm or 65%, see Table 4). On examining the beam width profiles it can be seen that these beams are particularly diffuse which makes it difficult to determine the edges of the beam and therefore the measurement is highly subjective to the individual making the measurement, as illustrated in Figure 5. For comparison, film 4 has well defined beam edges and this film has been measured within 11% (0.5 mm) by all readers as can be seen in Figure 6.

Figure 5 Image of film 1 which has a very diffuse edge and the corresponding beam profile determined by the software

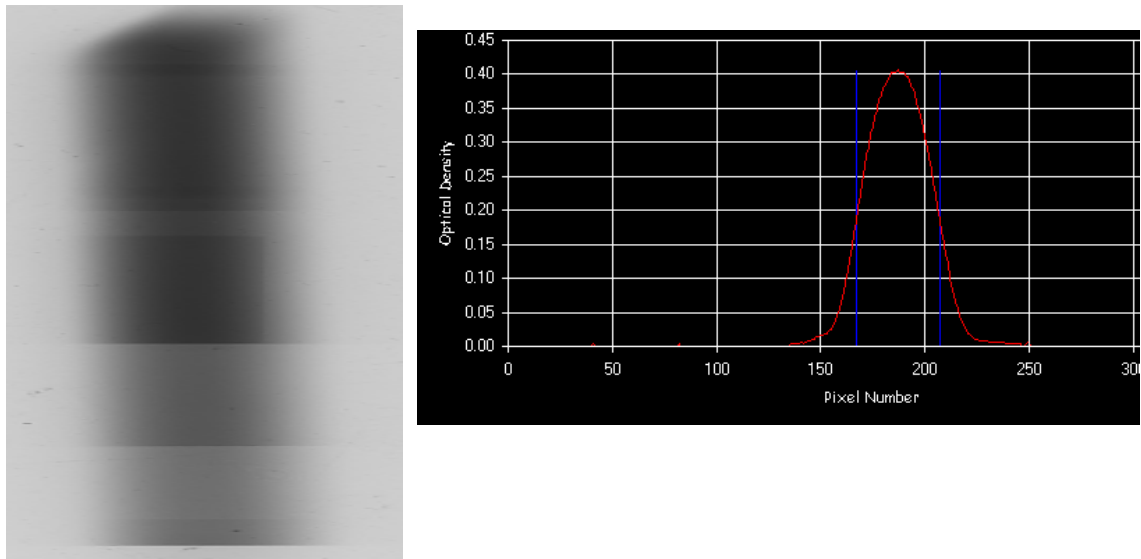
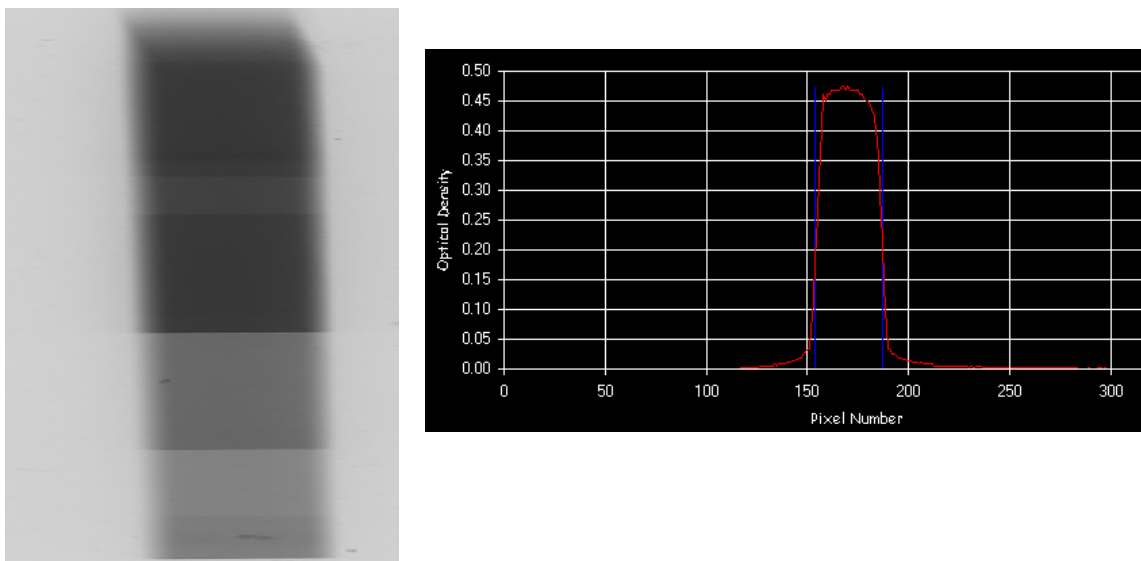


Figure 6 Image of film 4 which has a very sharp edge and the corresponding beam profile determined by the software



4.1.2 Reproducibility of the ruler method

The absolute measurement difference between the 1st and 2nd beam width measurements of the twenty test films are presented in table 5. Reader 4 shows a high correlation between repeated measurements, with only 3 out of 20 films having a difference in measurement of 1 mm or greater. Reader 3 has a difference of 1 mm or greater in reading 10 out of 20 films. The difference between measurements demonstrated the subjectivity of the ruler method. The differences in beam measurements between readers are considerable and these results demonstrate that the differences between successive measurements of a film by an individual are also significant.

TABLE 5 Absolute difference (in mm) between 1st and 2nd beam width measurements

Film Number	Reader 3	Reader 4
1	-0.5	0.0
2	-0.5	0.0
3	0	0.5
4	-0.5	-0.5
5	-1.5	0.0
6	-1	0.0
7	-1	0.0
8	-0.5	0.0
9	-1.5	0.0
10	-1	0.5
11	-1.5	0.0
12	-1	0.5
13	-1.5	0.0
14	-2	0.0
15	-1	1.5
16	-0.5	0.0
17	-0.5	1.0
18	-0.5	0.0
19	0	1.0
20	0	0.0
RMSE	1.0	0.5
Standard Deviation	0.6	0.5

4.1.3 Comparison of the light box and ruler method to the densitometer method

The differences between using the densitometer method and the light box and ruler method are presented in table 6. The RMSE error is seen to be 6% which shows good correlation between the two methods. The use of a light box and ruler is still a subjective measurement and to maintain good quality results would require the individuals performing the measurements to regularly check their results against standard films whose beam widths had been determined by a method similar to the densitometer method. A further experiment may be for several people to repeat the measurements using the light box method to establish whether this is an appropriate method, and can demonstrate good repeatability, or whether the good results observed in this experiment are due to the individual who carried out the measurements.

TABLE 6 Percentage difference between the densitometer method and using the ruler in combination with a light box

Film Number	% Difference
1	-2
2	-2
3	5
4	-6
5	2
6	-11
7	6
8	0
9	7
10	8
11	-7
12	-6
13	4
14	2
15	-14
16	9
17	-3
18	-3
19	4
20	-7
RMSE	6
Standard Deviation	6

4.1.4 Comparison of the digitised film method to the densitometer method

The differences between using the densitometer method and digitised images method are presented in table 7. The RMSE error is seen to be 7% which shows good correlation between the two methods. The width measured by the digitised image method is generally greater than that read using the densitometer method. The digitised image method uses an average of ten rows of data to account for small differences in the properties of the film. As the densitometer calculates an optical density for a single row of data it is more likely to be susceptible to small changes in the film and this may account for the differences seen in the width measurements.

TABLE 7 Percentage difference between the densitometer method and the digitised image method

Film Number	% Difference
1	2
2	7
3	2
4	6
5	7
6	7
7	6
8	10
9	7
10	11
11	8
12	6
13	4
14	9
15	0
16	6
17	8
18	6
19	6
20	3
RMSE	7
Standard Deviation	3

4.2 Beam height measurements

Panoramic X-ray beam heights are typically around 120 mm or 150 mm corresponding to the two heights of film cassette commonly used. As such it would be expected that this distance can be accurately measured using a ruler graduated in 1 mm steps. Additionally, the beam profile has well defined start and end points that can readily be measured between. The error in measuring the beam height was an RMSE of approximately 1% which indicates that both the digitised images method and the ruler method could be utilised for measuring panoramic beam heights.

5 CONCLUSION

The height of the X-ray beam can be accurately measured using all of the methods evaluated in this report. The simplest method, using only a ruler, can be adopted as the method of choice for this measurement. However, using a ruler alone cannot be considered a satisfactory method for the determination of panoramic X-ray beam width due to both the inaccuracy of the method and the subjectivity that has been clearly demonstrated in this report, both between different persons and the same people at different points in time. The use of a ruler, light box and magnifying glass may be considered an acceptable method, although if this method was to be adopted further evaluation should be carried out to ensure accuracy and consistency. This report has shown that the use of digitised images and transmission densitometry are satisfactory methods for the measurement of panoramic beam widths. DXPS has adopted the use of digitised images as this method offers a simpler and quicker automated measurement than the manual use of a transmission densitometer.

6 REFERENCES

- British Institute of Radiology (BIR), 2001. Assurance of quality in the diagnostic imaging department (2nd Ed). London: BIR.
- Doyle, P., Martin C.J., Robertson, J., 2006. Techniques for the measurement of dose width product in panoramic dental radiography. *Br. J. Radio.*, 79, pp.142-7.
- Hart, D., Hillier, M.C., Wall B.F., 2007. Doses to patients from Radiographic and Fluoroscopic X-ray Imaging Procedures in the UK – 2005 Review. HPA-RPD-029. Chilton: Health Protection Agency.
- Hewitt, J.M., 1984. The development and Operation of a Method for the Remote Determination of X-ray beam Parameters Used in Dental Radiography. NRPB-R164. London: HMSO.
- Institute of Physics and Engineering in Medicine (IPEM), 2005. Dental Radiography. In: Report 91: Recommended Standards for the Routine Performance Testing of Diagnostic X-ray Imaging Systems. Ch.9. York: IPEM.
- Isoardi, P., Ropolo, R., 2003. Measurement of dose-width product in panoramic dental radiology, *Br. J. Radiol.*, 76, pp.129-131.
- Tierris, C.E., Yakoumakis, E.N., Bramis, G.N., Georgiou, E., 2004. Dose area product reference levels in dental panoramic radiology. *Radiat. Prot. Dosim.*, 111, pp.283-7.
- Williams, J.R., Montgomery, A., 2000. Measurements of dose in panoramic dental radiography, *Br. J. Radiol.*, 73, pp.1002-6.