Assessment of dose-width products of pre-programmed exposure technique parameters in panoramic dental radiology: a comparison of methodologies

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ABSTRACT

The dose width product (DWP) at the receiving slit of a panoramic dental unit is indicative of the radiation dose a patient receives in a panoramic dental examination. It is a useful tool for assessing the pre-programmed exposure technique settings of a dental unit. Panoramic units are equipped with these parameters, but the radiation doses delivered to patients when these programs are activated are not well defined. This study assesses DWPs of pre-programmed exposure technique parameters at the receiving slit of a panoramic unit, using Gafchromic XRQA2 film which progressively darkens when exposed to radiation, and a pencil ionization chamber, which gives a direct readout of the DWP when an exposure is initiated. The exposed film is scanned into a desktop computer and the extent of colour change analysed with a free Java image processing program. The maximum percentage difference between the two methods for DWP estimation was less than 13%, consequently, Gafchromic XRQA2 film is regarded as suitable for DWP assessment in panoramic dental procedures. Although the DWPs of some of these exposure technique charts exceeded the recommended diagnostic reference level (DRL) of 65m Gymm; they were similar to published data from other researchers.

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ACRONYMS

ALARA: as low as reasonable achievable
DRL: diagnostic reference level
DWP: dose width product
IPEM: Institute of Physics and Engineering in Medicine
NRPB: National Radiological Protection Board

Key words: Panoramic dental unit, exposure techniques, Gafchromic XRQA2 film, diagnostic reference level, radiation doses

INTRODUCTION

Panoramic dental digital radiography exposes all the teeth and neighbouring structures of a patient to produce a single digital image. These units are equipped with preprogrammed exposure technique parameters for different patient sizes, to improve work flow and to reduce the need for repeat digital radiographs which would expose patients to unnecessary radiation. The total radiation quantity delivered to patients in panoramic dental examinations partially depends upon the exposure parameters which can be selected manually or derived from a pre-programmed set. Exposure parameters should deliver digital images with adequate diagnostic image quality while keeping radiation doses absorbed by patients as low as reasonable achievable (ALARA principle).

Napier[1] has recommended the dose width product (DWP) as the dose metric indicative of the total quantity of radiation delivered to patients during standard adult panoramic procedures. It is defined as the product of the absorbed dose in air over an exposure cycle and the horizontal width of the beam, both measured at the receiving slit of the panoramic dental unit. This is easy to ascertain and does not require the presence of a patient during assessment. It is therefore a reliable reference for limiting the dose and optimising image quality in any panoramic procedure. The National Radiological Protection Board (NRPB), in "Guidance notes for Dental Practitioners on the Safe Use of

X-ray Equipment"[2] and the Institute of Physics and Engineering in Medicine (IPEM) Report No. 88[3] recommend the DRL for DWPs as 65m Gymm for panoramic dental procedures. The DRL represents the third quartile value from the distribution of radiation delivered to patients for a particular procedure by a variety of X-ray machines - in this case panoramic dental units. It provides a means for clinicians and other interested parties to compare radiation exposures to patients from panoramic dental units by different manufacturers. In addition, it can serve as a tool to identify unusually high radiation exposures delivered to patients in standard panoramic procedures. The DWP does not take into consideration the height of the radiation beam. Different units may have slits of differing height which will affect the dimensions of the beam. Consequently, the IPEM Report No. 91[4] has endorsed the dose area product (DAP) as the dose metric for DRL in panoramic dental examinations. It is defined as the product of DWP at the image receptor slit and the height of the radiation beam at the image receptor slit.[5] Recently, many authors[6,7,8] have utilised the DWP at the receiving slit in reporting DRLs in panoramic dental procedures and some have reported values exceeding the recommended DRL of the IPEM Report 88. In a dental practice with a single panoramic dental unit, DWP is still an appropriate dose metric to evaluate pre-programmed techniques, as the height of the receiving slit is constant for all exposures. However, exposure techniques with DWPs exceeding the recommended DRL should be investigated with the DAP metric.

Gafchromic XRQA2 film[9] darkens when exposed to ion-iszing radiation, the film density being proportional to the quantity of radiation it receives. The film is self-processing and can be scanned with a standard flatbed document scanner.[10] It is sensitive over a dose range of one to–200mGy for radiation beams of 20 – 200 peak kilo voltage (kVp), where kVp represents the radiation beam energy.

A computed tomography (CT) pencil ionization probe, (Victoreen Model 500-200, high sensitivity 10cc CT ion chamber) consists of a chamber with a sensitive length of 100mm. It measures the integral dose delivered in an exposure cycle and provides a direct readout value of the DWP for a given set of exposure parameters.

AIM

This study assesses and compares the DWPs of pre-programmed exposure techniques of a panoramic dental unit (Planmeca Proline XC) using Gafchromic XRQA2 film and a CT pencil ionization chamber as assessment methods. The DWPs are also compared with the recommended DRL of the IPEM report 88 and with published data from other researchers.[6,7,14]

MATERIALS AND METHODS

Measurement of dose width products with a CT ionization chamber

A CT pencil chamber is calibrated in a secondary standard dosimetry laboratory, by exposing the entire length of the chamber in a known uniform radiation field. When a CT probe is placed perpendicular to the receiving slit of the secondary collimator, a partial volume of the probe is irradiated and charges are collected along the entire length of the probe. The DWP is estimated in accordance with a standard formula and is provided as a direct read out value.

With the standard 100mm long pencil probe, the CT dose index ($CTDI_{100}$) is a CT dose descriptor which represents the integrated dose along a dose profile (D_a (Z)) over the length of a pencil chamber and it is expressed as:

$$CTDI_{100} = \frac{1}{T}\int_{-50mm}^{+50mm} D_a(z)\, dz = \frac{f * E * f_{TP} * L}{T}$$

where f is the conversion factor from exposure (mR) to dose in mGy, E is the measured exposure, f_{TP} is the temperature and pressure correction factor, T is the nominal slice thickness and L is the length of the probe. The DWP is estimated according to this formula.: $DWP = f * E * f_{TP} * L$

A piece of film is placed on the receiving slit of the secondary collimator. An exposure is initiated to identify the centre of the slit. The CT probe is placed perpendicular to the slit, such that the centre of the CT probe is co-incident with the centre of the slit as shown in Figure 1. For each set of pre-programmed exposure technique parameters an exposure is activated and the value for the DWP is noted. It is repeated three times and the average is recorded as the DWP for that set of exposure parameters. This is repeated for all available pre-programmed exposure technique parameters for an average sized adult.

Figure 1: CT pencil ionisation chamber across the width of the receiving slit of the secondary collimator.

Measurement of dose width products with Gafchromic XRQA2 film

Sheets of Gafchromic® XRQA2 film (International Specialty Products Lot#: A10121202 and dimensions 10" x 12") are cut in rectangular pieces with dimensions 8.8cm x 1.8cm.

The CT pencil chamber is replaced with a piece of film as shown in Figure 2. The length of the film covers the entire height of the slit. An exposure is initiated with one of a set of pre-programmed exposure technique parameters and the film is placed in a marked envelope. The exposure parameters are noted. This is repeated three times with different pieces of film. The process is repeated for all available pre-programmed exposure technique parameters for an average sized adult. The films are scanned into a desktop computer with a flatbed document scanner 24 hours later while implementing the recommendation stated in Delic *et al.*[10] The image of each piece of film is analysed with ImageJ which is a free Java image processing program on the Internet.[11,12] It converts the net optical density of the film to pixel values.

The calibration equation for the conversion of film optical density to dose for this batch of films has previously been determined with an in-house method. This method utilises an ionization chamber whose calibration factor has been determined in a secondary standard laboratory and an X-ray unit whose performance is in compliance with the recommended tests from the Department of Health - Radiation Control, South Africa.[13] The calibration equation is given as:

$$Dose\ (mGy) = \frac{(34.693\ X\ NOD)}{(0.336 - NOD)}$$

where NOD is the net optical density of the film. The estimated error associated with the in-house calibration curve was less than 10% (Gy is a unit of radiation known as Gray and represents one joule of energy absorbed by one kg of tissue, 1 mGy = 0.001 Gy).

DATA ANALYSIS

Conversion of pixel values to Net Optical Density

When a radiation beam is incident on a Gafchromic XRQA2 film, the film darkens. The optical density is a measure of the amount of film darkening and is therefore a measure of the total radiation incident on the film. Unexposed films have inherent background optical density for which a correction factor must be determined, and the NOD is then expressed as a function of the pixel values, a measure of the light intensity. These calculations are made in accordance with a standard formula.

The Net Optical Density (NOD) corrects for the background optical density and it is expressed as:

$$NOD = \log\frac{I_o}{I_t} - \log\frac{I_o}{I_u} = \log\frac{I_u}{I_t}$$

where I_t is the intensity of the light transmitted through or reflected from the exposed film and I_u is the intensity of the light transmitted through or reflected from an unexposed film and I_o is a reference light intensity incident on the film. In ImageJ, the NOD is expressed as a function of the pixel values, where, a pixel value is a measure of the light intensity. Consequently, the above equation can be written as:

$$NOD = \log\frac{PV_{before}}{PV_{after}}$$

with PV_{before} = average pixel values of a given region of interest from an unexposed film and PV_{after} = average pixel values of a given region of interest, of the same size as that of the unexposed film.

Determination of the full width at half maximum (FWHM) of the NOD profile across the width of the slit as shown on the scanned image.

The NOD values obviously vary across the width of the film, the peak values being in the region where the film was superimposed over the columella slit. In order to produce a single value which represents the distribution, a calculation is undertaken. Consider first the image depicted in Figure 3a, which shows the darkened vertical rectangle of greatest exposure. A horizontal line is drawn across the image (Figure 3b) and the NOD values are recorded across the width of the image. Their distribution is shown in Figure 4 as a plot on a graph. Clearly the maximum occurs right over the position of the collimator slit. The graph is not a Gaussian curve and the single NOD reference value was therefore calculated as representing half of the maximum NOD value of the profile. The width at points where the NOD value is equal to this reference value is known as the "full width at half maximum (FWHM)" of the NOD values.

Isoardi *et al.*[14] utilised measurements from thermoluminescent dosimeters (TLDs) to compute the mean dose along the line profile across the width of the slit. They considered only values greater than the baseline value for absorbed dose determination. They also defined the average value of these TLD readings as the mean dose imparted to the film and determined the FWHM from the NOD profile of a film placed on the receiving slit of the secondary collimator. The DWP was calculated as the product of the mean dose and the FWHM.
This study utilises the same approach, where the mean NOD, which is representative of the radiation dose imparted to the film, is calculated as the mean of the NOD values above the baseline value sampled at 1mm along the x-axis. The mean NOD is converted to radiation dose (D_m) and the DWP is defined as the product of D_m and FWHM.

RESULTS AND DISCUSSIONS

The pre-programmed exposure technique parameters for an average sized adult are shown in Table 1. The DWPs of the pre-programmed exposure technique parameters are

Figure 2: A piece of film on the receiving slit of the secondary collimator.

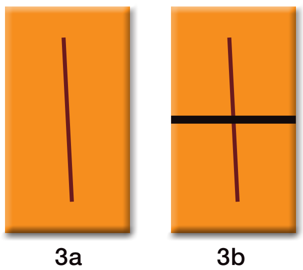

Figure 3: (a) An irradiated piece of film with the darkened region representing the interaction between the radiation beam across the receiving slit and the film. **(b)** The black line represents the profile along which the NOD measurements are recorded.

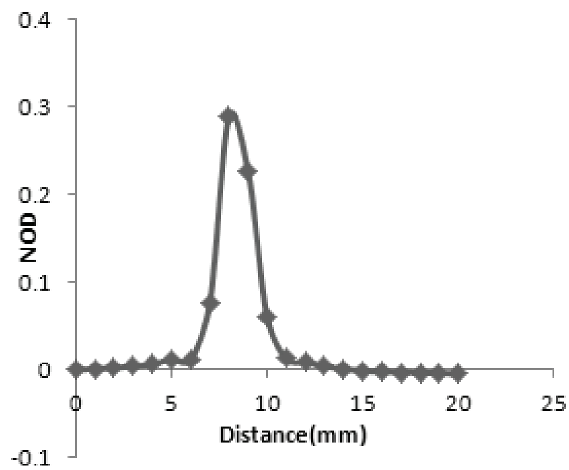

Figure 4: The NOD values of points along the horizontal line profile.

shown in Table 2, which includes data from both techniques. The greatest difference in measurement between the two methods is less than 13%. Figure 5 shows a plot of DWP measurements from the CT pencil chamber and from the Gafchromic XRQA2 film process for pre-programmed exposure parameters. The 45° trend line indicates a good correlation between the two methods (correlation coefficient >0.98). Hence Gafchromic XRQA2 film can be used for DWP measurements of pre-programmed exposure technique parameters of panoramic dental units. Moreover, the films are affordable and easy to use. The DWPs from the unit investigated in this study compare well with published data (Table 3). Walker C *et al.*[6] reported a DRL of 59.89 ±20.97m Gymm for adult panoramic radiographs in Irish dental practices while Lee JS *et al.*[7] have cited the highest DWP in their study as 148.9mGymm. The mean DWP of the current study was 91± 37.8mGymm, measured with the CT probe. The authors were informed that the exposure parameters of MODE 4 and 5 were rarely used for patient studies, nevertheless they recommended that pre-programmed exposure techniques with DWPs greater than 65mGymm should be investigated with the dose area product metric.

Table 1: Pre-programmed exposure technique parameters

MODE	kV	mA	seconds
1	62	5	18
2	64	7	18
3	66	9	18
4	68	11	18
5	70	12	18

Table 2: Comparison of dose width product (DWP) measurements of the pre-programmed technique exposure chart for an average sized adult using the panoramic Planmeca unit.

Parameters			CT probe	Film	% diff
kV	mA	secs	DWP mGymm	DWP mGymm	
62	5	18	43.1	47.9	10.2
64	7	18	66.3	69.7	4.8
66	9	18	92.3	88.5	4.3
68	11	18	118.6	105.0	12.9
70	12	18	136.4	132.3	3.1

Table 3: Reported dose width products of pre-programmed exposure technique parameters of some panoramic dental units from different manufacturers.[14]

Model	kVp	mA	Time (secs)	DWP mGymm
Planmeca PM 2002 (SIAS)	68	7	18	56.7
Planmeca PM 2002 (SIAS)	70	6	18	57.1
Planmeca PM 2002 (SIAS)	70	6	18	57.1
Planmeca PM 2002 (SIAS)	70	6	18	57.2
Orthophos (Seimens)	64	16	14.1	62.1
Rotograph 230 (FIAD)	70	10	13	173.6
Orthoralix C (Philips)	71	18.3	14	74.1
Orthoralix C (Philips)	71	18.3	14	74.1
Orthoralix C (Philips)	71	18.3	14	70.9

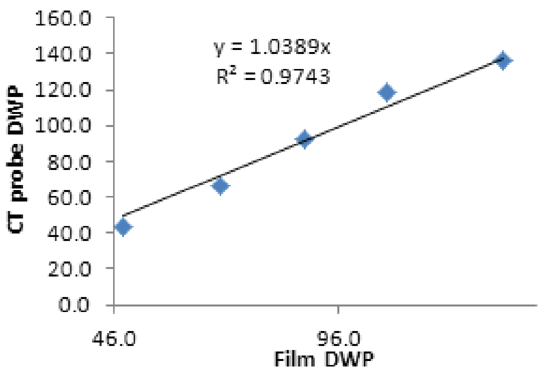

Figure 5: A plot of CT probe DWP and film DWP

CONCLUSION AND RECOMMENDATIONS

This study shows that pre-programmed exposure technique parameters of panoramic dental units should be investigated, and where necessary, dose and image quality optimisation processes should be implemented to ensure that the ALARA principle is upheld. The authors are committed to assess the DAPs of all future exposure parameters. Gafchromic XRQA2 film provides an inexpensive methodology for assessing these dose metrics which are necessary for optimisation of radiation protection in panoramic dental radiology. Moreover, it is highly probable that in the near future, these dose metrics will be required by the Department of Health-Radiation Control, South Africa for the licensing of all panoramic dental units.[15]

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