peer reviewed **ORIGINAL ARTICLE**

Dose reference level for barium enemas at state hospitals in the Western Cape South Africa

Caroline Nabasenja[1,3] *MTech Radiography* | **Florence Davidson**[1] *MTech Radiography*
Tobie Kotze[2] *PhD Physics* | **Penelope Engel-Hills**[1] *DTech: Radiography*

[1]*Cape Peninsula University of Technology*
[2]*University of Cape Town*
[3]*University of Namibia*

Abstract

Radiation doses for barium enema (BaE) examinations were measured using dose area product meters at three hospitals in the Western Cape in South Africa. Thirty adult patients, aged from 18 to 85 years, weighing 50-90 kilograms (kg), were included in the study. The mean age and weight of the patients were 58.3 years and 68.8 kg respectively. The mean DAP was 28.7 Gycm^2 and the third quartile DAP value was 36.5 Gycm^2. The mass of the patients, fluoroscopy time, and the use of digital or conventional fluoroscopy equipment, were the factors considered for dose variation between the three hospitals. The recommended dose reference level (DRL) for BaE at state hospitals in this region of South Africa is 36.5 Gycm^2.

Keywords

radiation protection, fluoroscopy, diagnostic reference level

Introduction

Barium enema (BaE) is a radiological examination of the colon where barium sulphate contrast medium is administered through the rectum to aid in radiological examination of the colon. This examination is indicated in congenital and inflammatory lesions, such as colitis, ulcerative colitis, Crohn's disease, ischemic colitis, diverticular disease of the colon, and tumours of the colon such as polypoid lesions.[1] Previously BaE was the routine radiological examination of the gastroinstestinal tract. However, with the advancement of radiological imaging modalities, such as computed tomography (CT), virtual colonography, magnetic resonance imaging (MRI), endoscopy, and ultrasound, with capabilities of tumour staging and high sensitivities for polyps and colon cancers, there is a decreasing frequency of BaE examinations.[2,3] Despite this BaE continue to be routinely performed in developing countries with less advanced modalities, and as an adjunct to failed or incomplete colonoscopy.[4,5]

The substantial biological and epidemiological evidence of radiation induced effects in man have motivated the concept of dose limits and control of radiation risks.[6] In the United Kingdom (UK), dose reference levels were adopted[7] to act as dose audits for quality control in radiology departments. In 1992, a Dosimetry Working Party in the UK devised national protocols that provided practical guidance for radiology departments in the use of these reference doses. In these protocols it was emphasised that departments must focus on dose levels for examinations that are most frequently performed and that contribute significantly to the collective dose and therefore the radiation risk.[8]

In South Africa (SA), protection of radiation workers and the public from unnecessary radiation exposure is continually emphasised.[9] Currently, it is a legal requirement for all fixed fluoroscopy equipment to have permanently fitted dose area product (DAP) meters thereby allowing real time monitoring of a patient's radiation dose during fluoroscopy examinations.[10] Having been identified as a large contributor to collective dose to the population from radiological examinations,[11,12] this study investigated radiation doses received by patients referred for BaE examinations at three state hospitals in the Western Cape in SA with the aim of identifying potential DRLs. The relationship between the measured radiation doses and the patients' mass, the fluoroscopy times, and use of conventional fluoroscopy or digital fluoroscopy units, were also investigated.

Materials and methodology

From June 2008 to May 2009, patient radiation dose measurements were performed at three state hospitals in the Western Cape. The radiation doses were measured using dose area product (DAP) meters that were permanently fitted onto the fluoroscopy units. The DAP meters were calibrated annually and also reset to zero for every new patient. Hospital 1 used a Philips conventional fluoroscopy (CF) unit that was operated by a radiologist with more than five years' experience. Hospitals 2 and 3 employed digital fluoroscopy (DF) units of Mecall and Philips models respectively: these were operated by radiology registrars. Quality assurance of the equipment was ensured by ascertaining from the individual equipment records that the equipment had passed the quality control tests.

In order to set DRLs, radiation dose measurements should be obtained from at least 10 patients weighing 50-90 kg.[8] Ten adult patients between the ages of 18 to 85 years, from each of the three state hospitals, who were referred for BaE and weighed from 50 to 90 kg, were included in the study. The measurements were obtained from 10 consecutive patients at each site thereby reducing sampling bias and ensuring a sample that is representative of the population presenting at state hospitals in this region of South Africa. Permission to conduct the study was obtained from the head of department of each of the three radiology departments. Ethics approval was granted by the Cape Peninsula University of Technology.

The patients provided consent to be included in the study.

Results

DAP values

Radiation doses were measured on 30 adult patients with a respective mean age and mass of 58.3 years and 68.8 kg. The DAP values recorded at the three hospitals are shown in Table 1. Site 3 recorded the lowest third quartile DAP value (22.6 $Gycm^2$). This DAP value was lower than the combined third quartile DAP (36.5 $Gycm^2$) of the three sites.

DAP and patients' mass

There was a weak linear correlation between patient mass and DAP value as shown in Figure 1 when the data from the three study sites were combined. The patient mass explained 30.45% (R^2=0.3045; p=0.02) of the DAP variation. When the patient mass and DAP value correlation were individually considered for the three study sites, the patient mass explained 59.60% (site 1: R^2=0.5960; p=0.009), 60.72% (site 2: R^2=0.6072; p=0.008) and 38.15% (site 3: R^2=0.3815; p=0.056) of the DAP variations as shown in Figures 2, 3 and 4 respectively. Distribution histograms of mass and DAP were plotted and showed a normal distribution of the data in Figures 5 and 6 respectively.

DAP and fluoroscopy time

There were no fluoroscopy times recorded at site 2 as the fluoroscopy unit indicated the time when a pulse of x-rays was activated and not the total fluoroscopy times (FT). The means and ranges for FT in minutes at sites 1 and 3 were 3.93 minutes (2.75 to 5.95 minutes) and 6.63 minutes (4.43 to 8.53 minutes) respectively. The combined mean fluoroscopy time was 5.28 minutes. Site 1 recorded a mean FT lower than the combined mean FT. There was no direct linear correlation between the DAP and FT with the FT explaining only 6.98% (R^2=0.0698; p=0.261) of the variation in the DAP values as shown in Figure 7.

Discussion

The mean age of the patients was 58.3 years with a mean mass of 68.8 kg. The mean weight obtained in this study is within the 65 kg to 75 kg weight range recommended by the DWP (1992) from which DRLs are determined. Engel-Hills and Hering[13] recorded mean age of 55.6 years and mean mass of 69.5 kg while investigating radiation doses for BaE in the Western Cape. The third quartile DAP value for BaE in this study was 36.5 $Gycm^2$ and this is therefore the recommended DRL for BaE in the Western Cape.

The trend to record lower DAP values in subsequent dosimetry studies in the same geographical location[14,15,16] owing to improved radiation protection procedures and installation of dose saving fluoroscopy equipment was observed in this work. There was a 56.5% (84 $Gycm^2$) radiation dose reduction when compared with a previous study in SA.[13] The ability of the DAP meter to integrate the absorbed dose over the whole beam area for the total exposure to the patient and provide a single measurement for BaE dose[8] allows the exclusive use of DAP measurements with-

Table 1. The mean, standard deviations and third quartile values DAP ($Gycm^2$) for BaE at the three study sites.

Study site	Number of participants	Mean DAP ($Gycm^2$)	STDEV DAP ($Gycm^2$)	Third quartile DAP ($Gycm^2$)
1	10	29.0	7.6	33.6
2	10	39.4	10.4	50.4
3	10	17.9	9.7	22.6
Combined	**30**	**28.7**	**12.7**	**36.5**

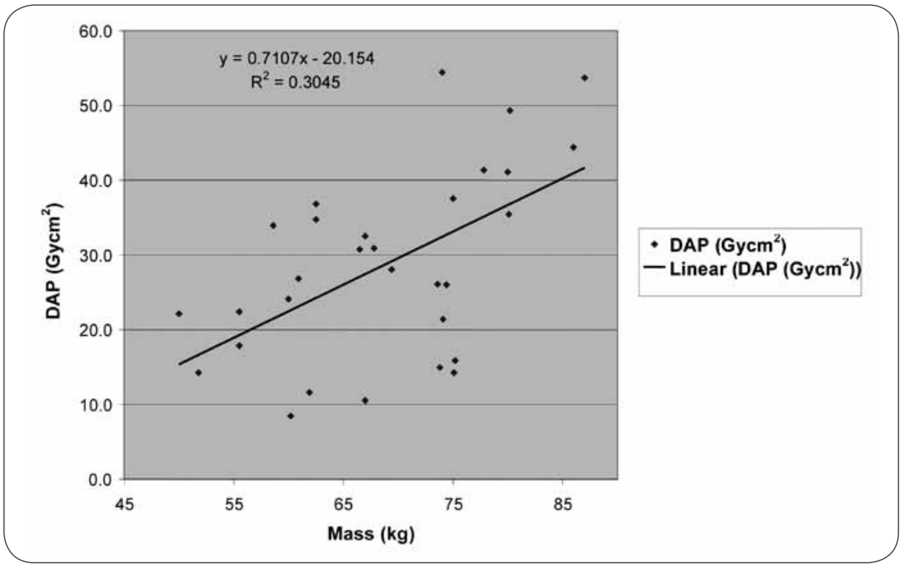

Figure 1. DAP versus mass for all BaE patients.

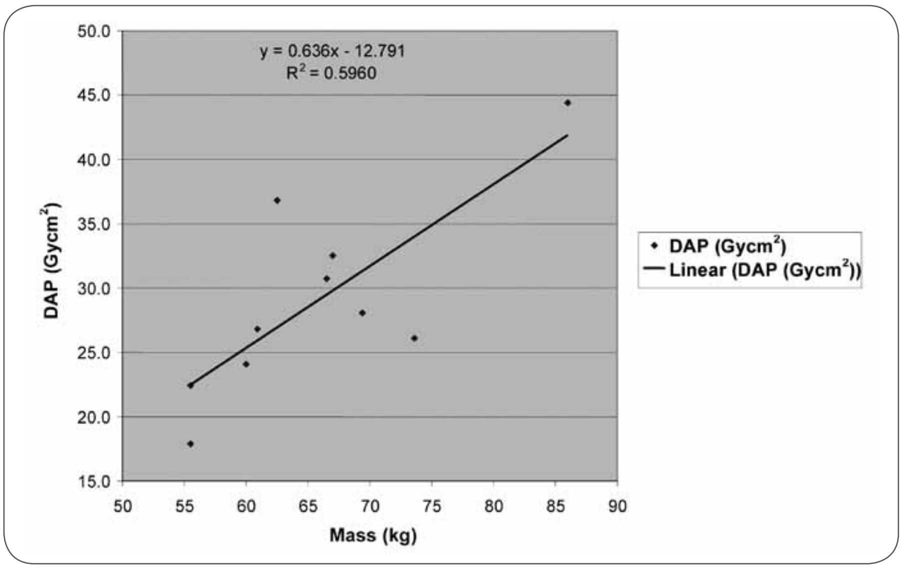

Figure 2. DAP versus mass for BaE at site 1.

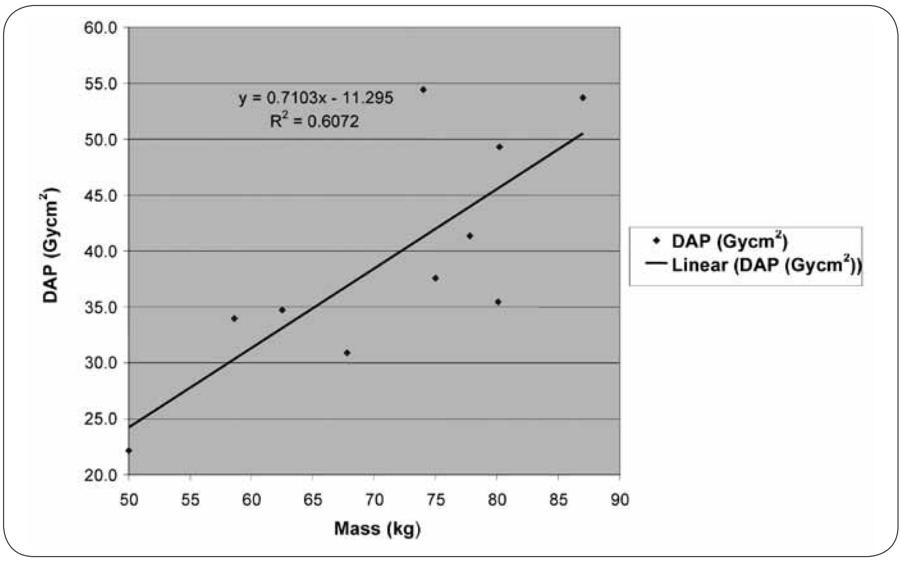

Figure 3. DAP versus mass for BaE at site 2.

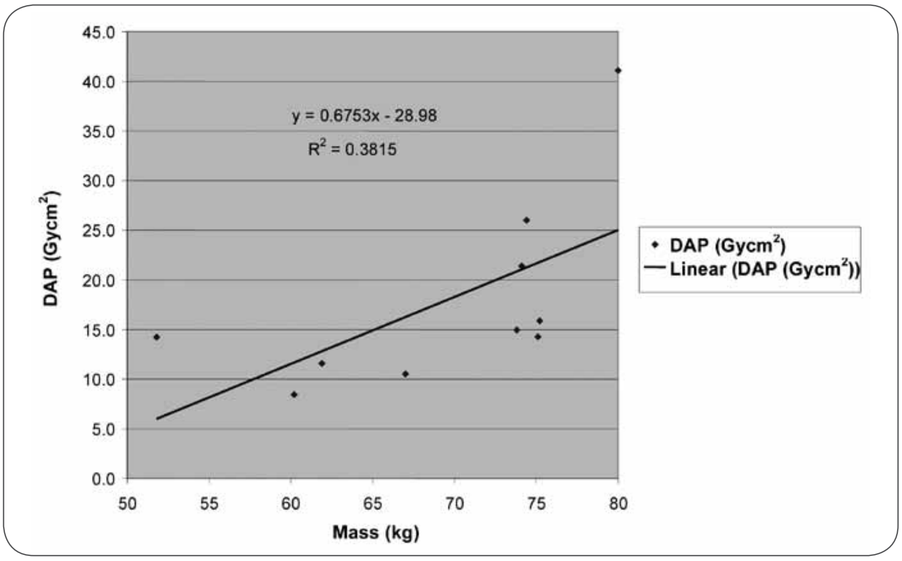

Figure 4. DAP versus weight for BaE at site 3.

out converting them to effective dose.[17] This saves the radiology personnel time converting DAP values to effective dose.

While clarifying the use and setting of DRLs, it was indicated that DRLs should not be used in a precise manner but rather as simple tests for identifying unusually high patient dose levels complementary to professional judgement. Additionally, DRLs should be easily measurable dose quantities above which equipment and procedures must be reviewed for radiation dose optimisation.[17,18] Furthermore, when dose data are collected from one or two hospitals, it should be used to monitor local trends in patient dose in order to establish compliance to the recommended DRL.[19]

Patient mass

Carroll and Brennan[20] as well as Warren-Forward et al.[21] found that patient mass contributed to 70% and 58% variation in DAP respectively. The study suggests that patient mass influences the DAP reading more at any individual site and fluoroscopy unit, compared to all sites averaged together. This can be seen by the R^2 that are higher for individual sites than for all the data grouped together. This may be attributed to the radiological findings during a BaE examination, which may require radiologists to adjust their technique, resulting in a higher or lower DAP reading. It may also be ascribed to the adoption of various screening techniques in the absence of a standard protocol applied at all the study sites, the level of experience of the radiologist performing the procedure as well

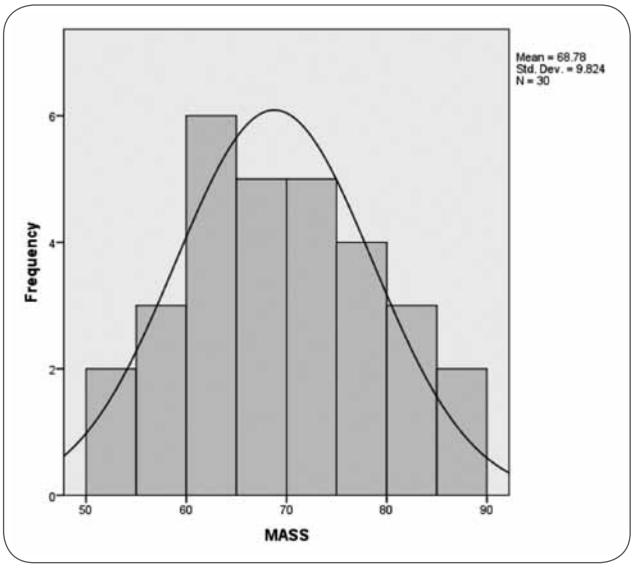

Figure 5. Distribution of mass of patients.
Mean = 68.78; Std. Dev. = 9.824; N = 30

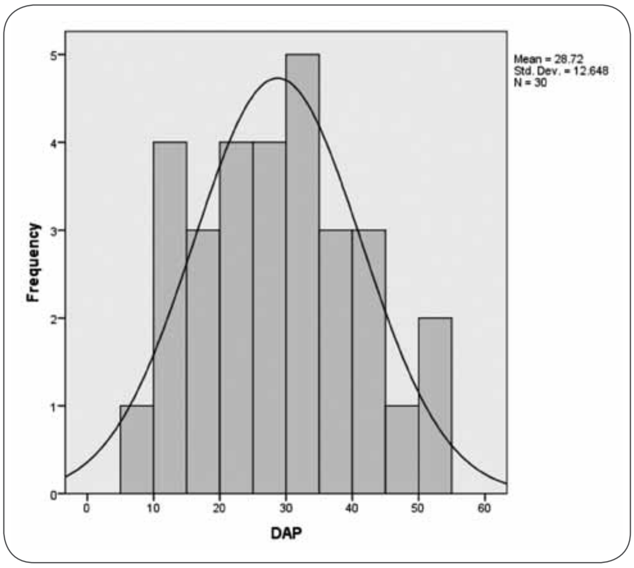

Figure 6. Distribution of DAP.
Mean = 28.72; Std. Dev. = 12.648; N = 30

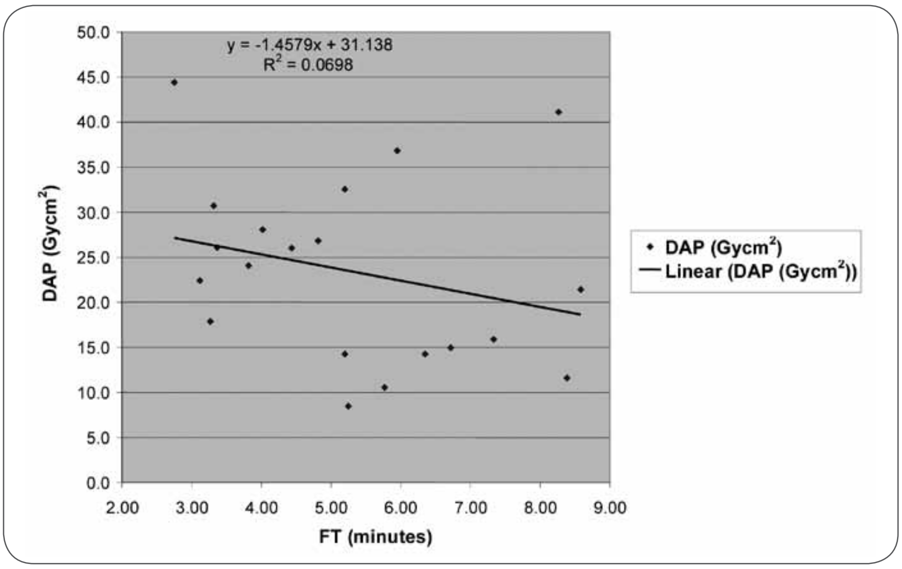

Figure 7. DAP versus FT for BaE at sites 1 and 3.

as dose saving capabilities of the equipment used. The employment of the same fluoroscopy unit for all BaE examinations at each study site may be responsible for change in the patient mass data affecting the DAP variation when the study sites were individually considered. The plotted histograms of mass (Figure 5) and DAP (Figure 6) showed a normal distribution. However, it is recommended that more data should be gathered in future studies to provide a more discerning distribution on the histogram.

Fluoroscopy time

Site 1 recorded a lower mean FT than site 3. The lower FT at site 1 was attributed to the radiologist, with more than 5 years' experience performing BaE, in contrast to the registrars performing the procedures at site 3. Yakoumakis et al.[22] found registrars to register FT of the order of 9.1 minutes compared to radiologists who recorded 3.2 minutes. Though the FT may be affected by the dynamic nature and findings of the examination, radiologists are capable of controlling the FT by modifying the technique used.[23,24] Contrary to the lower FT being associated with a reduction in DAP,[20,25] this was not observed in this study (Figure 7). This may be attributed to registrars operating the DF unit at site 3. The dose saving features of DF units allowed the registrars to record low DAP readings but high FT.

Digital versus conventional fluoroscopy units

Site 1 employed a CF unit while sites 2 and 3 employed DF units. Site 3 recorded a mean DAP value (17.9 Gycm^2) lower than those at site 1 (29 Gycm^2). The capacity of DF units to maintain lower doses than CF units was realised in this study. The radiology registrars, associated with long FT and high number of images,[21] maintained lower mean DAP values using the DF unit compared with the radiologist with more than five years' experience employing the CF unit. Broadhead et al.[26] recorded dose savings of almost 50% with DF (13.88 Gycm^2) compared with CF (25.35 Gycm^2).

Despite employing a DF unit with pulsed fluoroscopy capability and acquiring images at low mean frame rates of 7.5 pulses per second, associated with radiation dose saving,[27] site 2 recorded a mean DAP 26.4% higher than site 1. This high DAP value may be attributed to the high mA ranges (82 mA to 150 mA) employed on DF units to compensate for the image noise arising from low frame rates. With high mA settings the resultant dose does not decrease by the same amount as the frame rate. Mahesh[28] found a dose saving of 25% to 28% with a 50% decrease in frame rate. Such high mA settings, among other factors, such as registrars performing the BaE, may have caused the high DAP readings at site 2.

Conclusion

This paper discussed the radiation doses received by patients referred for BaE at three state hospitals in the Western Cape. The third quartile DAP value of 36.5 Gycm^2 was 56.5% lower than that obtained in an earlier study in the Western Cape.[13] The patient mass was responsible for 30% of the DAP variation with data from all three study sites combined. There were no direct correlations between the FT and DAP. This was attributed to comparing radiology personnel with different levels of training using different types of equipment. The capacity of DF units to record lower radiation dose than CF units was realised, with radiology registrars (associated with long fluoroscopy times), maintaining lower mean DAP values on the DF unit compared with a radiologist with more than five years' experience operating a CF unit.

Limitations of the study

This study was limited to three state hospitals. The sample size of this study was according to international recommendations for the calculation of a DRL on at least 10 participants of average mass 70 kg ±5.[8] A larger study would more conclusively determine the reasons for radiation dose variations measured.

Acknowledgements

The authors would like to acknowledge the Cape Peninsula University of Technology for funding the research project as a component of MTech: Radiography research. The heads of the radiology departments and staff at the three state hospitals as well the patients who participated in the research are acknowledged.

References

1. Bontrager KL, Lampignano JP. Textbook of radiographic positioning and related anatomy. 7th ed. Missouri: Mosby; 2010.
2. Caroline DF, Kendzierski RM. The stomach. In Adam A, Dixon AK, Grainger RG, Allison DJ. (eds.) Grainger and Allison's diagnostic radiology: a textbook of medical imaging. 5th ed. Volume one. Philadelphia: Churchill Livingstone; 2008.
3. Bartam CL, Taylor S. The large bowel. In Adam A, Dixon AK, Grainger RG, Allison, DJ (eds.) Grainger and Allison's diagnostic radiology: a textbook of medical imaging. 5th ed. Volume one. Philadelphia: Churchill Livingstone; 2008.
4. Tolan DJM, Armstrong EM, Chapman AH. Replacing barium enema with CT colonography in patients older than 70 years: the importance of detecting extracolonic abnormalities. AJR, 2007; 189 (5):1104-1111.
5. Sosna J, Sella T, Sy O, Lavin PT, Eliahou R, Fraifeld S, Libson E. Critical analysis of the performance of double-contrast barium enema for detecting colorectal polyps ≥ 6 mm in the era

of CT colonography. AJR, 2008; 190 (2): 374-385.

6. (ICRP) International Commission on Radiological Protection. History, polices, procedures. Annals of ICRP, 28 (supplementary 1):1-29, 1998.
7. RCR (Royal College of Radiologists) and NRPB (National Radiological Protection Board). Patient dose reduction in diagnostic radiology. Documents of the NRPB, Vol. 1, No. 3. Chilton: NRPB, 1990.
8. DWP (Dosimetry Working Party of the Institute of Physical Sciences in Medicine). National protocol for patient dose measurement in diagnostic radiology. Chilton: NRPB (National Radiation Protection Board), 1992.
9. South Africa. Public Health Act. Notice 1822 of 1973. Government Gazette, 98(3991): 1-12, August 3, 1973.
10. DoH SA (Department of health South Africa). Radiography conditions (excluding radiotherapy simulators) - Annexure to licence. http://www.doh.gov.za/department/radiation/licencing/electronicproducts/conditions/radiography.pdf [accessed 04 April 2014] 2006.
11. Hart D, Wall BF. UK population doses from medical X-ray examinations. European J of Radiology. 2004; 50: 285-291.
12. Kaul A, Bauer B, Bernhardt J, Nosske D, Veit R. Effective doses to members of the public from the diagnostic application of ionizing radiation in Germany. European Radiology. 1997; 7: 1127-1132.
13. Engel-Hills PC, Hering ER. Dose-area product measurements during barium enema radiograph examinations-a Western Cape study. SAMJ,2001; 91(8): 693-696.
14. Hart D, Hillier MC, Wall BF. Doses to patients from radiographic and fluoroscopic x-ray imaging procedures in the UK-2005 review. Chilton: Health Protection Agency-Radiation Protection Division (HPA-RPD)-029. 2007.
15. Hart D, Hillier MV, Wall BF. Doses to patients from medical X-Ray examinations in the UK: 2000 review. Chilton: NRPB – W14/ National Radiological Protection Board. 2002.
16. Hart D, Hillier MC, Wall BF, Shrimpton PC, Bungay D. Doses to patients from medical x-ray examinations in the UK-1995 review. London: HMSO (Her Majesty's Stationery Office), NRPB-R289. 1996.
17. Matthews K, Brennan PC. The application of diagnostic reference levels: general principles and an Irish perceptive. Radiography. 2008; xx: 1-8.
18. (ICRP) International Commission on Radiological Protection. Radiological protection and safety in medicine, ICRP publication 73. Annals of the ICRP, 26(2). 1996.
19. Wall BF. Diagnostic reference levels-the way forward. BJR, 2001; 74(885): 785-788.
20. Carroll EM, Brennan PC. Radiation doses for barium enema and barium meal examinations in Ireland: potential diagnostic reference levels. BJR, 2003; 76:393-397.
21. Warren-Forward HM, Haddaway MJ, Temperton DH, McCall IW. Dose-area product readings for fluoroscopic and plain film examinations, including an analysis of the source of variation for barium enema examinations. BJR, 1998; 71: 961-967.
22. Yakoumakis A, Tsalafoutas IA, Sandilos P, Koulentianos H, Kasfiki A, Vlahos L, Proukakis C. Patient doses from barium meal and barium enema examinations and potential for reduction through proper set-up of equipment. BJR, 1999; 72: 173-178.
23. Vehmas T, Lampinen JS, Mertjarvi A, Rannikko S. Factors influencing patient radiation doses from barium enema examinations. Acta Radiologica. 2000; 41: 167-171.
24. Verdun FR, Aroua A, Trueb PR, Vock P, Valley J-F. Diagnostic and interventional radiology: a strategy to introduce reference dose level taking into account the national practice. Radiation Protection Dosimetry. 2005; 114(1-3):188-191.
25. Horton D, Cook AM, Taylor AD. Audit in action: a significant reduction of double-contrast barium enema screening time with no loss of examination quality. BJR, 1992; 65: 507-509.
26. Broadhead DA, Chapple CL, Faulkner K. The effect of digital imaging on patient doses during barium studies. BJR, 1995; 68(813): 992-996.
27. Trapp JV, Kron T. (eds). An introduction to radiation protection in medicine. New York: Taylor & Francis; 2008.
28. Mahesh M. Fluoroscopy: patient exposure issues. RadioGraphics. 2001; 21: 1033-1045.