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ORIGINAL ARTICLE

Radiation Dose Reduction for Barium Enema: an Achievable Improvement in Patient Care

BMH Lai, VKP Fung, JSF Shum, ANL Sy, SCS Cheng, JLS Khoo

Department of Radiology, Pamela Youde Nethersole Eastern Hospital, Chai Wan, Hong Kong

ABSTRACT

Objective: *To evaluate the effectiveness and practicality of dose-reduction measures for double-contrast barium enema based on well-established UK National Reference Levels.*

Methods: *Between May 2009 and February 2011, 369 patients were prospectively studied with respect to radiation doses received while undergoing double-contrast barium enema examinations before and after implementation of radiation dose-reduction measures. Statistical analysis was performed on fluoroscopic screening times, dose-area-product, and the number of undercouch and overcouch films used during the examination.*

Results: *A significant reduction in fluoroscopic screening time (43%) was achieved after implementation of dose-reduction measures ($p < 0.01$). Similarly, a 40% reduction in dose-area-product was achieved at the end of the study ($p < 0.01$). Before the implementation of the dose-reduction measures, the mean dose-area-product and fluoroscopic screening time at our centre were at 73% and 58% above the UK National Reference Levels, respectively. At the end of the study, they were noted to be up to 13% lower than the UK standards.*

Conclusion: *A 40% reduction in radiation dose on patients undergoing double-contrast barium enema was achieved after implementation of dose-reduction measures in our hospital. The double-contrast barium enema radiation dose was also reduced from 73% above the UK National Reference Level to a level below this reference standard.*

Key Words: *Barium; Enema; Radiation dose*

中文摘要

鋇劑灌腸攝影中降低放射劑量：病人照料方面的改進

賴銘曦、馮啓邦、岑承輝、施雅倫、鄭志成、邱麗珊

目的：按英國國家參考水平建議來評估在雙重對比鋇劑灌腸攝影中把放射劑量降低的措施的效用及實用性。

方法：本前瞻性研究的對象是於2009年5月至2011年2月期間，369名接受雙重對比鋇劑灌腸檢查的病人。找出他們在放射劑量降低措施實行前和後所接受放射劑量水平的情況。用統計分析方法研究病人的熒光屏照射時間、劑量面積乘積、及檢查過程中使用檢查床下膠片和檢查床上膠片的數量。

Correspondence: *Dr BMH Lai, Department of Radiology, Pamela Youde Nethersole Eastern Hospital, 3 Lok Man Road, Chai Wan, Hong Kong.*
Tel: (852) 2595 6177 ; Fax: (852) 2975 0432 ; Email: billylai@gmail.com

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結果：實行降低放射劑量的措施後，熒光屏照射時間顯著減少43%（$p < 0.01$），而劑量面積乘積亦同樣下降40%（$p < 0.01$）。實行措施前，本中心的平均劑量面積乘積和熒光屏照射時間比英國國家參考水平建議的分別高出73%和58%。接近研究尾聲時，兩項數據都比建議的水平減低了13%。

結論：實行降低放射劑量措施後，接受雙重對比鋇劑灌腸檢查的病人接受放射劑量減少了40%。而放射劑量的水平，亦由措施前高出英國國家參考水平73%回落至參考水平以下。

INTRODUCTION

Double-contrast barium enema (DCBE) is one of the most commonly performed fluoroscopic examinations in daily radiological practice, but is associated with significant radiation exposure and potential health hazards. With increasing public awareness and concern about such radiation risks, it is crucial that procedures are performed according to the "as low as reasonably practicable" (ALARP) principle. Dose optimisation is necessary to prevent excessive unnecessary radiation exposure to the patient.

The United Kingdom has well-established guidelines for acceptable radiation levels for common radiological examinations and it is a legal requirement to adhere to them.[1] Hong Kong has yet to develop its own guidelines in this regard, but the UK guidelines are a good source of reference. A study was conducted to compare our radiation levels for DCBE with the well-established UK National Reference Levels (NRL). The effectiveness of the subsequently implemented dose-reduction measures on DCBE was also evaluated.

METHODS

A prospective study was conducted from May 2009 to February 2011 on radiation doses received by patients undergoing DCBE examinations in a local tertiary referral centre (Pamela Youde Nethersole Eastern Hospital, Hong Kong) before and after implementation of radiation dose-reduction measures.

The study design (Figure 1) comprised four phases. The first phase consisted of an internal audit of radiations dose for DCBE from May to August 2009. Radiologists and radiographers were concealed from knowledge about this audit. Data concerning fluoroscopic screening time, dose-area-product (DAP), number of undercouch and overcouch films used during examinations, the performing radiologist, the years of training received and the radiologist's fellowship status were collected. Such data were used as a baseline reference representing normal practices before implementation of dose-reduction measures.

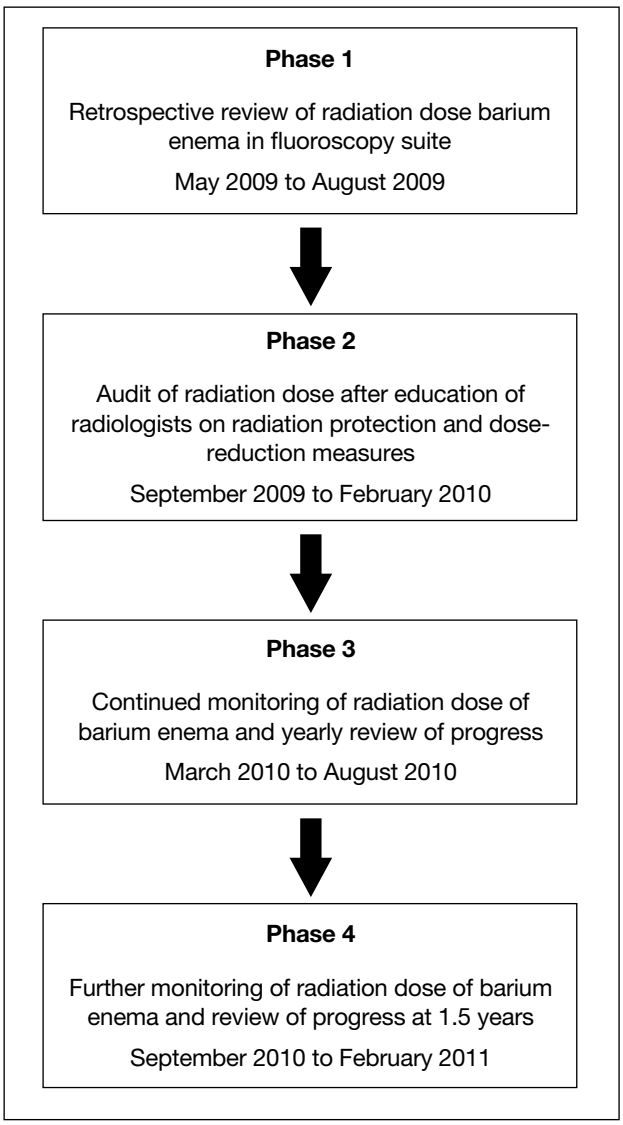

Figure 1. Flowchart of the study design.

During the first two months of phase 2 of the study, education and training were given to radiologists on dose-reduction methods. Such methods included removal of grid during filling phase, coning, and use of intermittent fluoroscopy. Data collected during this two-month period were not used for subsequent analysis to allow radiologists time to adjust to new protocols. Subsequent audit of radiation doses was conducted

from November 2009 to February 2010. Results were reviewed at the end of this phase during a departmental meeting on an analysis of unnamed groups.

Further monitoring of radiation doses was continued and reviewed at half-yearly intervals, constituting phase 3 (March – August 2010) and phase 4 (September 2010 – February 2011) of the study. Reminders on dose-reduction measures were given half-yearly at departmental meetings on an unnamed group basis.

All examinations were performed in our designated fluoroscopic suite using a Siemens Luminos TF fluoroscopy machine. The performing radiologists consisted of both fellows and trainees with varying degrees of experience. Examinations were performed by different radiologists on a daily rotational basis to ensure a variety of case difficulties and avoidance of machine-related variations during this 1.5-year study. The National Diagnostic Reference Level in the Year 2000 Review published by the UK National Radiation Protection Board was used as a reference standard[2] for comparison of our results. Statistical analysis was performed using SPSS version 10.

RESULTS

A total of 369 cases were included in the study. The majority of DCBE cases (89%) were performed by trainees. First- and second-year trainees were most involved (49% and 26%, respectively). The degree of involvement of each category of radiologist during various phases of study is shown in Table 1 and Figure 2. No significant trend was observed with respect to the seniority of the radiologist and the phase of study ($p = 1.00$).

Radiology Doses and Filming Practices among Trainees and Fellows

No significant difference was observed in DAP ($p = 0.13$), screening time ($p = 0.45$), number of overcouch films ($p = 0.89$) between fellows and trainees. Fellows did, however, tend to take one less undercouch films than trainees ($p < 0.01$), with a mean of seven films as compared to eight films by trainees. No significant difference was observed in DAP, screening time, number of undercouch and overcouch films used by trainees with different years of experience.

Radiation Doses Before and After Dose-reduction Measure Implementation

Prior to implementation of new dose-reduction measures, the mean fluoroscopy screening time and mean DAP at our centre were 58% and 73% above the UK NRL, respectively (Table 2). The collective mean DAP and screening time for the post-implementation phases were 38% and 32% lower than the original values ($p < 0.01$).

Table 1. Radiologist involvement.

Year of radiology training	No. (%) of cases
1	182 (49)
2	95 (26)
3	49 (13)
Fellow	43 (12)

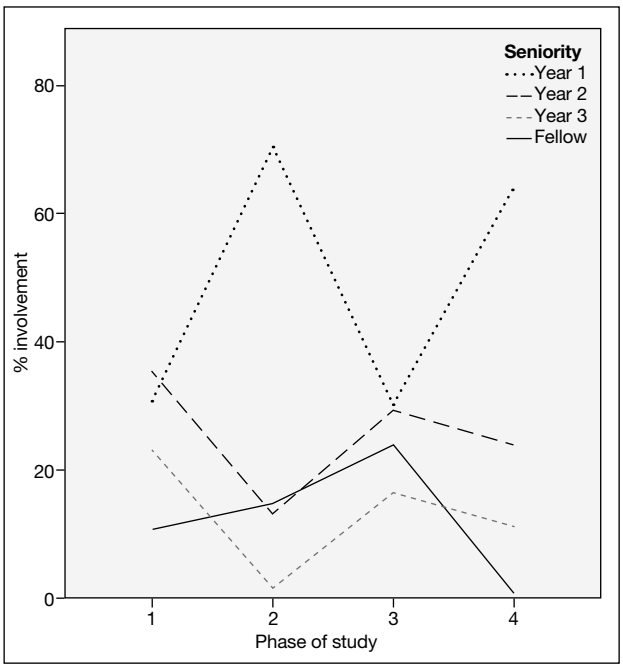

Figure 2. Percentage involvement of radiologists during different phases of the study.

Detailed subgroup analysis of the post-implementation phases showed a continual reduction in fluoroscopic screening time and DAP during the 1.5-year follow-up period (Table 3, Figures 3 and 4). At the end of the study (phase 4), our screening time was 13% below the UK NRL, whereas our DAP was only slightly below the UK reference level.

Radiation Doses Adjusted for Potential Covariates

Analysis of covariance (ANCOVA) was performed to mitigate any potential confounding effects of the radiologist's training experience and FRCR status on DCBE dose results throughout various phases of the

Table 2. Pre- versus post-implementation dose-area-product, screening time, and film usage.*

Phase of study	Pre-implementation	Post-implementation	Interval change†	p Value
No. of cases	65	304	-	-
Mean DAP (% difference from UK NRL)	73.1	17.8	-55%	<0.01
Mean screening time (% difference from UK NRL)	58.2	-3.1	-61%	<0.01
No. of undercouch films used	9.1	8.2	-0.9	0.02
No. of overcouch films used	7.8	8.3	+0.5	<0.01
Fellow involvement (%)	10.8	11.8	-	1.00

Abbreviations: DAP = dose-area-product; NRL = National Reference Levels.
* ANOVA with Bonferroni adjustment.
† Negative values denote levels below the UK NRL, and positive values levels above the UK NRL; UK NRL Reference[2] for DAP: 31.3 cGym^2, screening time: 161 seconds.

Table 3. Dose-area-product and screening time as percentage difference from UK National Reference Levels in different phases of the study.*

	Phase of study			
	1 (Pre)	2 (Post)	3 (Post)	4 (Post)
No. of cases	65	61	109	134
Mean DAP (% difference from UK NRL)	73.1‡	39.6†	27.7†	-0.4†
Mean screening time (% difference from UK NRL)	58.2†	16.8†	-2.2†	-13.0†

Abbreviations: DAP = dose-area-product; NRL = National Reference Levels.
* ANOVA with Bonferroni adjustment; negative values denote levels below the UK NRL, and positive values levels above the UK NRL; UK NRL Reference[2] for DAP: 31.3 cGym^2, screening time: 161 seconds.
† p<0.01
‡ p<0.05

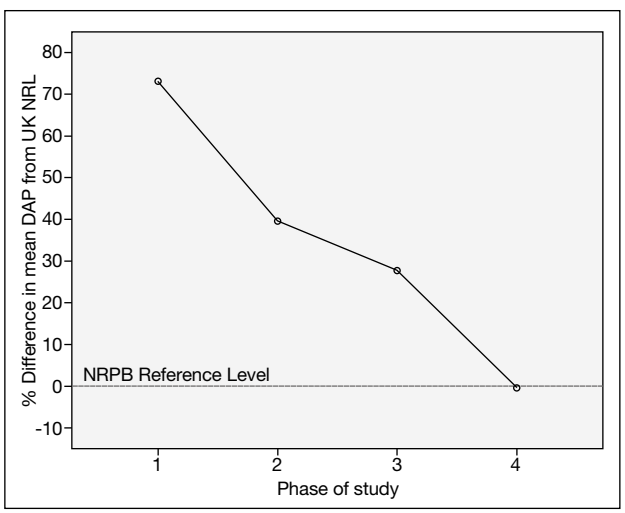

Figure 3. Trend of dose-area-product during various phases of the study.
Abbreviations: DAP = dose-area-product; NRPB = National Radiation Protection Boards; NRL = National Reference Levels.

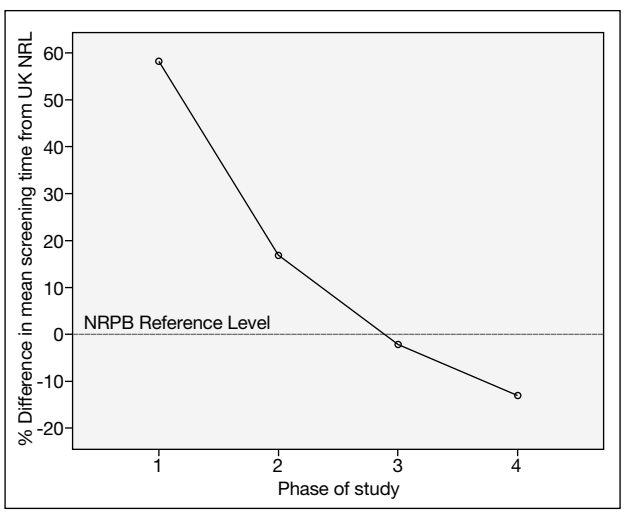

Figure 4. Trend of screening time during various phases of the study.
Abbreviations: NRL = National Reference Level; NRPB = National Radiation Protection Boards; NRL = National Reference Levels.

study. Results from ANCOVA showed that neither of these were significant predictors of DAP or screening time.

Conversely, the phase of study was a significant predictor of both DAP and screening time (both $p < 0.01$) even after adjustment for the above two factors (Table 4). In brief, after mitigating the effects from potential

Table 4. Percentage changes in dose-area-product (DAP) and screening time among different phases of study.*

	Phase of study		
	2 vs. 1	3 vs. 1	4 vs. 1
% reduction in mean DAP	17.3	25.0†	39.5†
% reduction in mean screening time	24.2‡	35.3†	43.3†

* ANCOVA with Bonferroni correction, adjusted for years of training of radiologist, FRCR fellowship status.
† p<0.01
‡ p<0.05

cofounding factors, analysis showed a significant reduction of 43% in fluoroscopic screening time in phase 4 as compared to phase 1 ($p < 0.01$). Similarly, a 40% reduction in DAP was achieved at the end of the study ($p < 0.01$) after adjusting for seniority and FRCR status.

Undercouch and Overcouch Film Usage

The average number of undercouch films was reduced by about one film in the post-implementation phase ($p = 0.02$), whereas, the number of overcouch films increased by 0.5 films ($p < 0.01$). However, no significant change was observed in the total number (undercouch + overcouch) of films taken: 16.5 films (phase 1) vs. 16.8 (post-phase 1), $p = 0.45$. During subgroup analysis of various phases of the study, no statistically significant difference was observed in either the total number, or individual counts of undercouch or overcouch films used in the various phases of the study.

DISCUSSION

Although barium enema is one of the most commonly performed fluoroscopic studies in routine radiology practice, it is associated with significant radiation exposure. Our study has shown that a dose reduction of more than 40% is achievable by application of simple radiation protection measures, including removing the anti-scatter grid during the filling phase, and using adequate coning and intermittent fluoroscopy. This has led to a reduction in radiation received by the patient, and very likely also by the staff.

Although the use of anti-scatter grids improves image resolution, the radiation dose received by the patient is also higher. For the majority of patients, radiation exposure during filling phase is only intended to help the radiologist guide the barium column to its destination, the caecum. Application of the anti-scatter grid to produce high-dose high-quality images is of little additional diagnostic value in this situation. In many fluoroscopy machines, the grid can be automatically applied or removed at the touch of a button. Hence the grid can be reapplied quickly during filling or any phase of examination, if any significant abnormality is detected and deemed necessary. As one of our dose-reduction measures, we changed the barium enema protocol on our fluoroscopy machine to start by default with the 'grid-off' mode. This has greatly helped to avoid incidental high-dose screening by the radiologist during filling phase. Diagnostic image quality during subsequent undercouch and overcouch filming phases were unaffected as the grid was reapplied, simply by touching a button just before spot and overcouch images were obtained.

Aside from educating our radiologists on the appropriate use of grids, the use of intermittent fluoroscopy was emphasised to reduce unnecessary screening time and DAP. Only intermittent screening is required to note the progress of the barium column during the filling phase, continuous screening rarely being justified. Similarly continuous exposure is unnecessary while awaiting adequate bowel distension during undercouch filming and during drainage of barium from the rectum. Adequate coning is also an important means of dose reduction. Education and reminders on its importance were given in this regard, to both the performing radiologist and radiographers, to avoid excessive radiation in areas outside the region of interest.

As with many other radiology training centres, the majority of cases of DCBE were performed by trainees, with first-year trainees being most involved. On average, Fellows tended to take one less spot film than trainees, however, on the whole, no significant difference in DAP and screening time was observed, possibly related to the small number of cases performed by Fellows. In our analysis using ANCOVA, FRCR Fellowship status and training experience were used as adjusting variables to mitigate the potential effects they may have had on the DAP and screening time results. They did not turn out to be significant variables accounting for variations in DAP and screening time.

In our study, the extent of reduction in screening time with reference to the UK standard did not bring about a similar degree of change in the percentage difference in our DAP from the UK NRL. This is understandable as a number of factors other than screening time affect the DAP. According to Warren-Forward et al,[3] screening time only accounts for about 25% of the DAP value. In our study therefore, despite the screening time being 13% below the UK standard at the end of our study, our DAP values were only slightly below the UK reference levels. This was possibly because the total number of under- and over-couch films used in our study remained largely unchanged during the study period. In Warren-Forward et al's study,[3] the total number of films used also accounted for 18% of the variation observed in DAPs. This factor has a significant influence on DAPs, only slightly less than that of screening time. As the usage of additional spot and overcouch films increases

radiation exposure to the patient,[3] further research is suggested to assess the possibility of reducing the total number of such films per examination and its effect on diagnostic quality of the DCBE, overall DAP and screening time. Interestingly, despite there being no significant change in the total number of films used, during the period of implementation of post–dose-reduction measures, there was a reduction in the average number of undercouch 'spot' films taken, while a small increase was observed in the number of over-couch films used per examination. This may be due to a change of practice with regard to the filming method of the lateral rectum. Further research to investigate the cause of this phenomenon and its effects on DAP and screening time is recommended.

CONCLUSION

A 40% reduction in radiation dose on patients undergoing DCBE has been achieved after implementation of dose-reduction measures in our hospital. The DCBE radiation dose has also been reduced from 73% above the UK NRL to a level below this reference standard. Further research is recommended to assess the possibility of further reducing the number of films per examination and the consequential effect on diagnostic quality of the DCBE, and overall DAP and screening time.

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