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ORIGINAL PAPER

Selective anti-scatter grid removal during coronary angiography and PCI: a simple and safe technique for radiation reduction

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Abstract *Objectives* The aim of this study was to quantify the radiation dose reduction during coronary angiography and percutaneous coronary intervention (PCI) through removal of the anti-scatter grid (ASG), and to assess its impact on image quality in adult patients with a low body mass index (BMI). *Methods* A phantom with different thicknesses of acrylic was used with a Westmead Test Object to simulate patient sizes and assess image quality. 129 low BMI patients underwent coronary angiography or PCI with or without the ASG in situ. Radiation dose was compared between both patient groups. *Results* With the same imaging system and a comparable patient population, ASG removal was associated with a 47% reduction in total dose-area product (DAP) ($p < 0.001$). Peak skin dose was reduced by 54% ($p < 0.001$). Operator scatter was reduced to a similar degree and was significantly reduced through removal of the ASG. Using an image quality phantom it was demonstrated that image quality remained satisfactory. *Conclusions* Removal of the ASG is a simple and effective method to significantly reduce radiation dose in coronary angiography and PCI. This was achieved while maintaining adequate diagnostic image quality. Selective removal of the ASG is likely to improve the radiation safety of cardiac angiography and interventions.

Introduction

Imaging used in coronary angiography and percutaneous coronary intervention (PCI) needs to be balanced with minimizing radiation exposure to staff and patients through application of the principle of ALARA (as low as is reasonably achievable) [1, 2]. Cardiologists practice many techniques for reducing radiation doses. These include reducing the fluoroscopy frame rate, limiting use of cineangiography, optimizing patient and X-ray equipment positioning, avoiding extremely angulated projections and minimizing use of magnification [3, 4]. More recent additions to radiation lowering techniques include real-time digital fluoroscopy recording, real time radiation monitoring devices [5, 6], and disposable radiation hats and shields [7]. Of equal importance is the use of appropriately sized personal protective equipment such as lead aprons, eyewear and thyroid collars.

The image quality provided by most modern catheterization laboratories is now well above what is required for high quality images, technical success and safe completion of the procedure. With these improvements in imaging systems it may be possible to safely reduce radiation doses in low or normal weight patients translating to significant dose reductions over the lifetime of both cardiology patients and interventional staff.

The anti-scatter grid (ASG) is situated at the input of the image detector on an X-ray imaging system (Fig. 1). The primary function of the ASG is to absorb scatter radiation emitted by body tissues before reaching the detector plate in order to increase image contrast and resolution. ASG's consist of alternate strips of an X-Ray absorbing material, such as lead, and a comparatively non-absorbing interspace material, such as carbon fibre or aluminium. Due to their constituents, however, ASGs also reduce the intensity of

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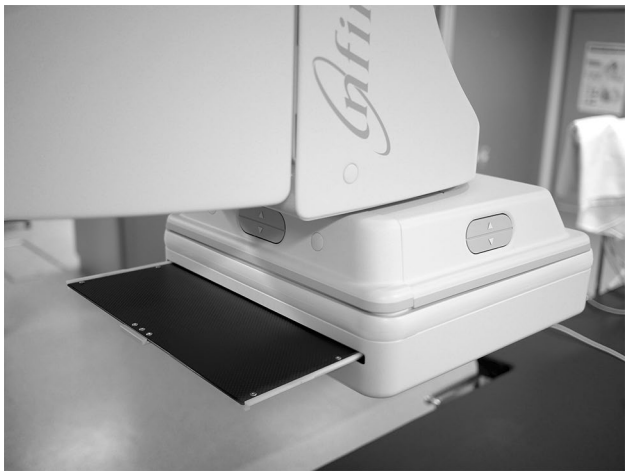

Fig. 1 The anti-scatter grid (ASG) can be removed or re-inserted rapidly from the input of the imaging detector

radiation forming the image. To counter this and to maintain consistent image quality the automated exposure control system increases the output of the imaging system to ensure sufficient photons are recorded by the detector. The result is a net increase in radiation output from the imaging system and therefore an increase in dose [8]. As the dose is increased, so is exposure to the patient, operator and staff. We theorized that in procedures where image quality demands are modest, such as in low Body Mass Index (BMI) patients, it may be reasonable to reduce patient and staff exposure by removing the ASG.

The hypothesis of this study is that removal of the ASG in low weight patients is a simple and rapid technique for delivering significant reductions in radiation dose to both patients and staff without compromise of image quality.

Methods

Phantom image quality assessment

Image quality assessment was first performed to assess the impact of ASG removal on image quality and radiation dose in different simulated patient sizes. To achieve this a Westmead Fluoroscopic Test object (WTO) (Fig. 2a) and a line pair test phantom (Fluke Biomedical, Cleveland, Ohio) (Fig. 2b) were both loaded with varying acrylic thicknesses of 10, 15 and 20 cm with these simulating patient sizes of ~40, 60 and 80 kg respectively [8, 9]. The WTO was used to assess image quality parameters of contrast threshold (CT), and low-contrast resolution (LCR). The line pair test object was used to assess high-contrast resolution (HCR). Both objects were placed at the centre of the acrylic load to simulate coronary angiography (Fig. 3) A focal detector distance of 125 cm and a table height of 100 cm were used. Assessment of image quality was performed in fluoroscopy mode and cine mode for each acrylic thickness both with and without the grid. Assessment was made in the anterior-posterior (AP) projection. Parameters recorded for each acrylic thickness were dose area product (DAP), kV, mA, and pulse width (ms). Image quality assessment was

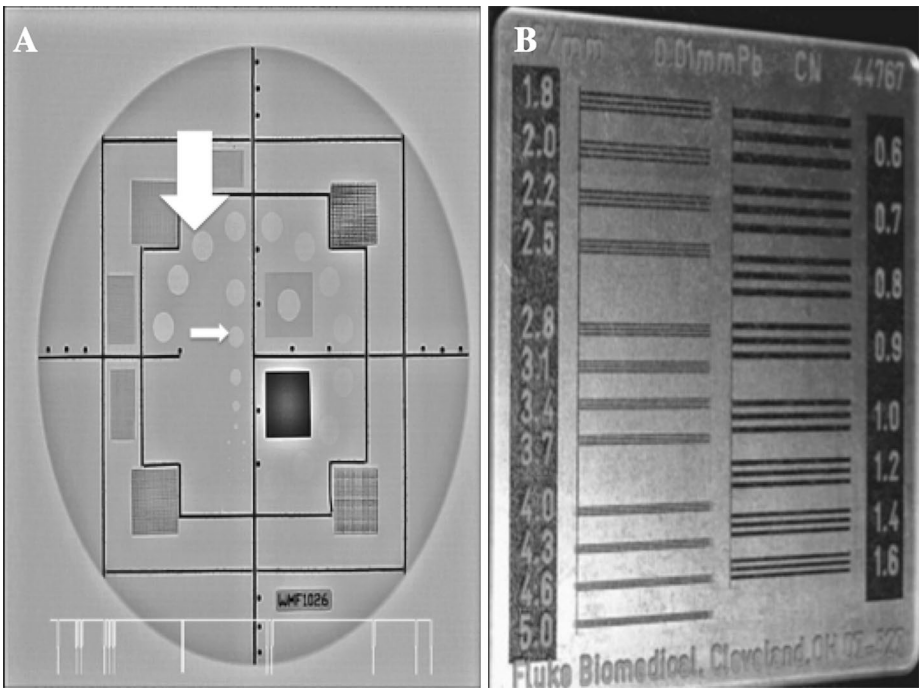

Fig. 2 **a** Cineangiography of a Westmead Fluoroscopic Test Object at 15 frames per second (f/s): low contrast resolution (LCR) is the number of large peripheral discs visible out of a maximum of 15 (*large arrow*), contrast threshold (CT) is the number of smaller central circles visible (*small arrow*). **b** Image of a line pair phantom object used to assess high contrast resolution (HCR)

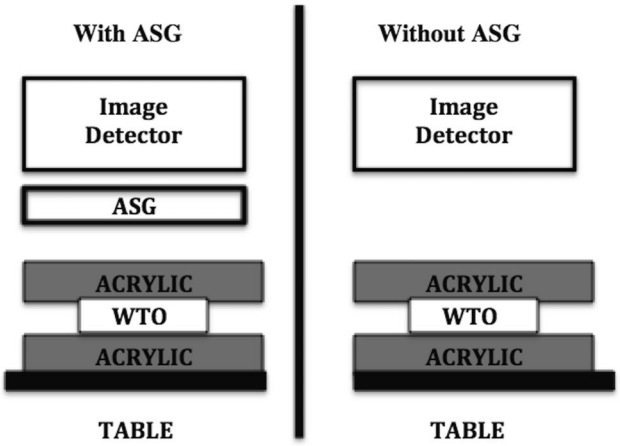

Fig. 3 Experimental arrangement for phantom image quality assessment; WTO was used to assess LCR and CT parameters but was substituted for a line pair object to assess HCR

performed by an experienced Interventional Cardiologist who was blinded to the protocol and assessed image quality during live images. Each measurement was performed in triplicate.

Operator dose scatter assessment

An InMed dosimeter (Unfors Raysafe, Uggledalsvägen, Sweden) was used to investigate the effect on operator scatter dose with the ASG removed. The dosimeter is regularly calibrated and serviced. The dosimeter was placed at a height of one metre where the operator would normally stand. Dosimeter readings were measured with and without the grid in three projections; anterior posterior (AP), left anterior oblique (LAO) 30° and right anterior oblique (RAO) 30°. Imaging system parameters were: fluoroscopy rate 10 frames per second (f/s), cine rate 15 f/s, focal detector distance125cm, table height 100 cm, reference point to dosimeter distance 100 cm. An acrylic load of 20 cm was placed at the centre of the table to simulate scatter from a patient. No radiation shields were used during testing. All measurements were taken in triplicate.

Patient studies

A total of 129 low or normal BMI patients (BMI < 25 kg/m^2) undergoing coronary angiography and/or PCI were enrolled in the study. Initially 69 consecutive patients were enrolled with the ASG in situ. Subsequently 60 patients had procedures with the ASG removed. During enrolment of these patients there were 209 patients screened of which 71 had a BMI < 25 kg/m2. Of these 71 eligible patients, 60 were successfully recruited. The study was non-randomized. The operator was not blinded to the allocation and could at any time request the ASG be reinserted if they felt image quality was non-diagnostic. A single cardiac imaging system was used for all procedures (*Infinix-I*, Toshiba Medical Systems, Otawara-shi, Tochigi-ken, Japan). Radiation dose data and demographic variables were compared between the two groups. Performance of angiography was left at the discretion of the operator. Patients with previous bypass grafts and those undergoing fractional flow reserve measurements were excluded.

A number of radiographic dose parameters were recorded and compared between the two groups. These were defined as:—(i) *Peak skin dose* is the highest dose at any portion of the patients skin as defined by the Toshiba Dose Tracking System (Toshiba Medical Systems, Japan) [10] (ii) *reference point air kerma* is the accumulated energy extracted from the X-ray beam per unit mass of air at the predefined interventional reference point (close to the patient's entrance skin surface) [11], (iii) *cumulative dose area product* (DAP) is the total energy emitted from the entire X-ray tube, (iv*) number of cine acquisition exposures* is the duration of cine acquisition multiplied by the cine frames per second, vi) *fluoroscopy time* is the total duration of fluoroscopy used during the case. Data for these studies were collected prospectively into a purpose-designed registry used for quality assurance and outcomes research purposes. Ethics approval was granted by the local human research ethics committee.

Statistical analysis

Sample size calculations were based on observational data from our cardiac catheterization laboratories over a 12-month period. The sample size was calculated assuming an alpha of 0.05, beta of 0.2 and 50% reduction in DAP with the ASG removed. It was calculated that 59 patients in each group would be required. Statistical analysis was performed with SPSS version 22 software (IBM Company, Chicago, IL). For the phantom image quality assessments results are expressed as a mean and compared using the repeated measures t-test. For the patient clinical studies results are expressed as number (%) or median (interquartile range). Comparison between groups with the ASG removed was performed using the Mann–Whitney U-Test. A p-value of <0.05 was considered to be statistically significant.

Results

Phantom image quality assessment

At each phantom size the image quality was higher with cine than fluoroscopy although better image quality was

associated with higher radiation dose (Table 1). With increasing phantom size there was deterioration in image quality in both fluoroscopy and cine.

At the smallest phantom size (10 cm acrylic) with the ASG removed there was no significant difference in image quality and radiation dose was 56% lower for fluoroscopy and 36% for cine ($p=0.03$) (Fig. 4a, b). There was a progressive deterioration in image quality with ASG removal at increasing phantom size. At the intermediate phantom size there was a borderline reduction in image quality during fluoroscopy with removal of the ASG (CT, $p=0.035$ and LCR, $p=0.07$). However, there was significant dose savings without the ASG; 62% during fluoroscopy ($p<0.001$) and 60.4% during cine ($p<0.001$).

At the largest phantom size there was a significant impact on image quality with ASG removal. During fluoroscopy and cine there was lower CT ($p=0.02$ and $p=0.02$ respectively) and lower LCR ($p=0.015$ and $p=0.038$) when the ASG was removed. HCR was not statistically significant between groups. There remained an even greater

Table 1 Phantom image quality assessment

	Small (10 cm)				Medium (15 cm)				Large (20 cm)			
	Grid		No Grid		Grid		No Grid		Grid		No Grid	
	Fluoro	Cine	Fluoro	Cine	Fluoro	Cine	Fluoro	Cine	Fluoro	Cine	Fluoro	Cine
Image quality assessment												
HCR (Ip/mm)	2.6	2.7	2.5	2.7	2.5	2.8	2.2	2.5	2.3	2.5	2.0	2.2
CT (Out of 14)	11	13	9	12	11	12	8	11	9	11	7	9
LCR (Out of 10)	10	10	9	10	10	10	8	10	8	10	6	8
Radiation output												
DAP (mGy/min)	2.5	31.2	1.1	20.1	6.6	81	2.5	32.1	16.7	205.9	4.9	46
Radiographic factors												
kV	80	75	80	63	80	77	80	74	80	76	80	76
rnA	25	162	15	160	51	227	23	160	97	356	42	206
Pulse width (ms)	4.0	2.0	3.1	2.0	5.8	3.5	3.9	2.0	8.1	5.9	5.2	2.9

CT in % contrast. HCR in line pairs per millimeter (lp/mm). LCR the smallest hole size visible in the contrast detail section of the test object. Dose expressed in DAP/pulse (mGy.cm2)

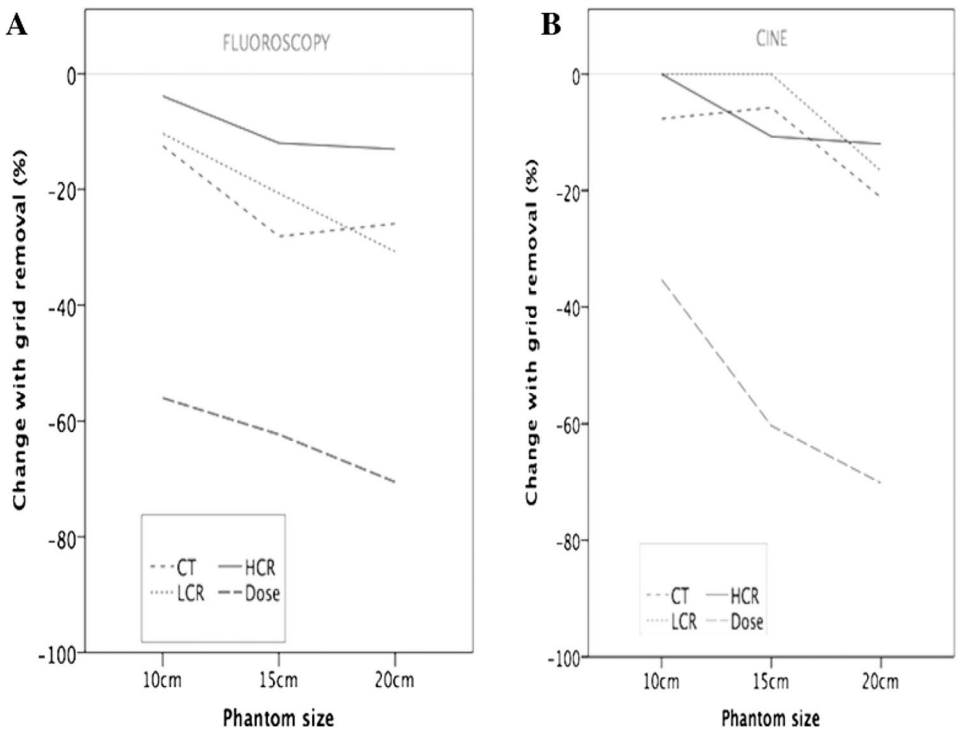

Fig. 4 Phantom image quality assessment compared in Fluoroscopy (**a**) and Cine (**b**). CT in % contrast. HCR in line pairs per millimeter (lp/mm). LCR the smallest hole size visible in the contrast detail section of the test object. Dose expressed in DAP/pulse (mGy.cm^2)

reduction in dose in the largest phantom size when the ASG was removed; 70% during fluoroscopy ($p < 0.001$) and also 70% during cine ($p < 0.01$).

These data clearly show that removal of the ASG provides significant radiation dose reduction and as phantom size increases the image quality deteriorates. At all phantom sizes the image quality remained above local authority requirements [12].

Operator dose scatter assessment

Scatter was assessed using an InMed dosimeter (Unfors Raysafe, Sweden) in the AP, LAO 30° and RAO 30° projections. In the AP projection the removal of the ASG during fluoroscopy reduced radiation dose by 57.3% (Table 2). Similar 49.8% dose reduction was seen during cine. Scatter dose saving through removal of the ASG was even more prominent in the LAO and RAO projections. Fluoroscopic dose in LAO was reduced by 58.7%, cine dose in LAO by 56.3%, fluoroscopy dose in RAO by 75.4% and cine dose in the RAO by 55.5%. Therefore it is likely that removal of the ASG reduces the radiation dose to the proceduralist by a similar magnitude as total dose emitted by the tube.

Clinical results and dose reduction to patients

A total of 129 patients were recruited at a single centre. Angiography alone was performed in 90 patients and the remainder underwent coronary angiography with percutaneous coronary intervention (PCI) and stent insertion. No patients had previous coronary artery bypass grafts and all fulfilled the criteria of BMI less than 25. When PCI was performed it was successful in all cases and an average of 1.36 stents (range 0–3) were inserted.

The ASG was in situ for 69 patients and removed for 60 patients. There was no difference in demographic variables between the two groups with the exception of a slightly higher BMI with the ASG removed (Table 3). With the ASG removed there was no cases where the interventionalist requested re-insertion due to inadequate image quality. There was no difference in immediate procedural outcomes between the groups. With the ASG removed compared with the ASG in situ there was a 46.62% reduction in radiation dose (Fig. 5). There was also lower peak skin dose without changes in other procedural radiation indicators such as fluoroscopy time or number of cine exposures.

Table 2 Operator dose scatter with and without the anti-scatter grid (ASG)

Cine acquisition	ASG in (uGy/sec)	ASG out (uGy/sec)	p value
AP0/0°	754 ± 65.7	378 ± 30.3	p = 0.001
LAO 30°	1184 ± 99.7	517 ± 25.1	p < 0.001
RA030°	1890 ± 84.5	840 ± 45.2	p < 0.001
Fluororoscopy			
AP0/0°	82 ± 1.7	35 ± 3.1	p < 0.001
LA030°	109 ± 7.1	45 ± 2.4	p < 0.001
RA030°	240 ± 19.1	59 ± 1	p < 0.001

Results expressed as a mean ± SD

Discussion

This study has shown that removal of the ASG is additional strategy to significantly lower radiation dose in normal or low BMI patients. This was done without compromising image quality. During coronary imaging, radiation exposure can have significant detrimental effects [13, 14]. These can be deterministic effects such as skin damage or cataract formation or random stochastic effects including the risk of malignancy [15]. It is now generally accepted that all efforts to reduce radiation dose should be made wherever possible.

With increasing case complexity patients are being exposed to higher radiation doses [14]. There are a number of reasons that may prompt the operator to discontinue a procedure including progress during the case, likelihood of success, contrast burden and increasing radiation dose. Selective removal of the ASG may therefore permit longer procedure duration with a greater chance of success. Phantom studies demonstrated a greater deterioration in image quality during fluoroscopy when compared to cineangiography. The maintenance of cineangiography image quality with the smallest phantom size may be due in part to a fall in kV. These findings are relevant as during coronary angiography and PCI the majority of procedural decisions are made based on cineangiography.

Gridless coronary angiography has been used in pediatric cardiology for some time [16]. With improvements in imaging system technology its use has also been proposed in the adult cardiac electrophysiology field [8]. It was first introduced in adult interventional cardiology by Partridge et al. [17] in 2006 through the concomitant use of an air–gap technique. A limitation of this technique was that it involved a time consuming re-configuration of the imaging system using a line-pair phantom and changing the focus to detector distance.

It is important to highlight that unlike the previous study [17] examining gridless imaging in adult coronary angiography there was no need to adjust the focal detector distance or recalibrate the imaging system settings in our study. Therefore this technique is extremely easy to use. Grid removal and replacement can be performed efficiently during a case without affecting sterile covers

Table 3 Comparison of patient demographics and comparison of radiation variables with ASG removal

Baseline characteristics	Overall	ASG in	ASG out	Significance
Patients	129	69	60	
Patient characteristics				
Age (years)	70 (60–80)	68 (59–76)	73 (62–80)	p = 0.335
Male (n, %)	91, (71)	50, (72)	41, (68)	p = 0.70
Height (cm)	169 (160–177)	170 (162–178)	165 (160–173)	p = 0.059
Weight (kg)	63 (58–71)	64 (57–72)	63 (58–71)	p = 0.748
BMI (kg/m^2)	23 (21.2–23.9)	22.6 (21.1–23.7)	23.2 (21.3–24.4)	p = 0.036*
Procedural variables				
Radial access (n, %)	103, (80)	51, (74)	52, (87)	p = 0.08
Stent insertion (n, %)	39, (31)	20, (29)	19, (33)	p = 0.703
Radiation variables				
Fluoroscopy time (min)	6.9 (2.8–13.4)	6.9 (32-14.1)	7.1 (4.1–13.1)	p = 0.566
Cine Exposures (n)	12 (10–26)	11 (9–24)	12 (10–27)	p = 0.540
Cine Frames (n)	812 (650–1124)	831 (684–1061)	785 (626–1140)	p = 0.560
Air Kerma (mGy)	275 (177–455)	385 (262–600)	200 (111–343)	p < 0.001*
Peak skin Dose (mGy)	110 (55–177)	138 (92–234)	64 (37–113)	p < 0.001*
DAP (mGy/min)	23 (13.5–37.6)	29.4 (22.3–44.5)	152 (112−25)	p < 0.001*

BMI Body mass Index (kg/m^2), *DAP* Dose Area Product (mGy/min) Values represent median (interquartile range)

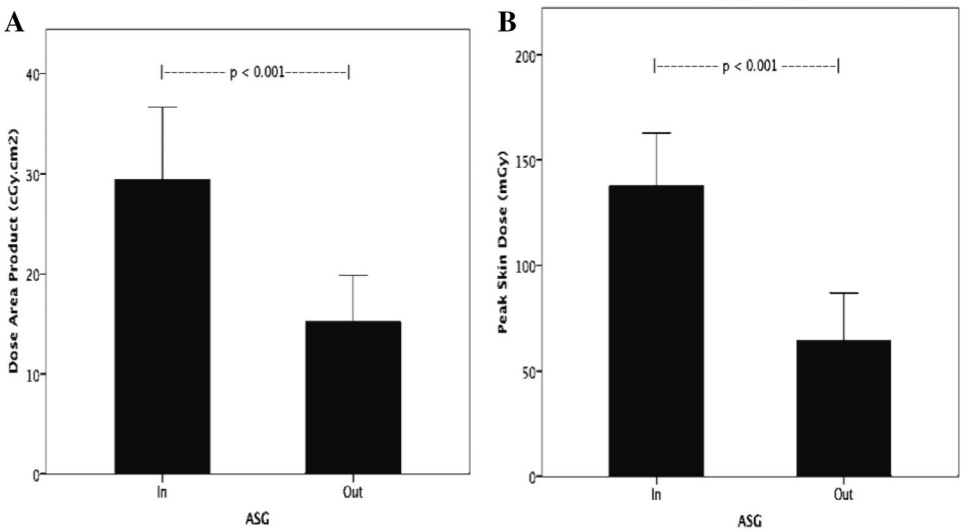

Fig. 5 Comparison of **a** Dose-area product (DAP) and **b** Peak skin dose with and without the ASG in situ. *Bars* represent median and *error bars* 95% confidence interval

and is done via a port on the front of the detector housing (Fig. 1). Removal of the ASG is not equivalent to simply reducing the energy output of the tube with the expectation of maintaining image quality. The ASG removes non-parallel or scattered photons. However, it absorbs a proportion of parallel and aligned photons. Removal of the ASG results in a greater number of aligned (as well as scattered) photons reaching the detector for a equivalent tube output. This explains why, with ASG removal in low BMI patients, image quality does not appreciably deteriorate despite the significant reduction in dose (i.e. the same number of aligned or nearly aligned photons reach the detector at a lower tube output). This also explains why simply reducing the tube output whilst keeping the ASG in situ will result in a disproportionate fall in image quality. Furthermore, the detector input dose may fall below minimum manufacturer requirements.

Our study was performed using a Toshiba Infinix *I* system, which has an easily removable grid. Currently not all coronary imaging systems have the ability to remove the ASG. According to the standardization documents for interventional radiology equipment [18], the ASG should be easily removable. Future directions may include customization based on BMI and this would include grid removal for

low BMI patients and variation in grid morphology as BMI increases [19].

In the phantom studies it was shown that ASG removal impacts image quality at higher weights. Depending on patient demographics at different catheterization laboratories this technique will have variable applicability. In this circumstance, however, reducing dose, where possible, may be even more important in the lifetime risk of interventional staff. This technique has the ability to be applied to other interventions however this study did not evaluate its use in structural or peripheral interventions.

Limitations

A limitation of this study is that BMI was used as a surrogate for chest wall thickness. We chose the BMI cut-off of less than or equal to 25 from preliminary phantom image quality assessment using different thicknesses of acrylic to simulate different patient BMIs. Whether chest wall thickness is a greater influence on ASG removal was not assessed in this study. The recruitment of patients in the clinical study was non-randomized and complex statistical analysis to correct for all known confounding variables was not performed due to the limited sample size. Additional potential sources of bias are the lack of consecutive patient enrolment and lack of blinding of the proceduralist to ASG assignment. Whilst there is the potential for selection bias as well as known and unknown confounding variables to influence the results, the dose savings were consistent with those seen in the phantom studies. This trial was powered as a pilot study to quantify the dose reduction and feasibility of ASG removal. A larger study would be required to assess procedural outcomes.

Conclusion

Selective use of ASG removal for coronary angiography and percutaneous coronary intervention in normal or low BMI patients is a safe, simple and effective way of achieving meaningful radiation reduction to both patients and interventional staff.

Compliance with ethical standards

Conflict of interest GI has accepted travel support from Toshiba Medical Systems to attend conferences.

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