

# **Influence of the calibration conditions of radiochromic film on the measurement of peak skin dose in interventional radiology**

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## ABSTRACT

### Purpose:

25 The evaluation of Peak Skin Dose (PSD) is a key issue for patient radiation dose management in interventional procedures. The impact of radiochromic films calibration on PSD measurements in pulsed fluoroscopy was investigated under various kVp and additional filtration conditions.

### Methods:

30 Films were calibrated free-in-air for six beam qualities ( $kVp_{\text{mmCu+mmAl}}$ :  $70_{0.1+1}$  ;  $90_{0.1+1}$ ;  $90_{0.4+1}$ ;  $120_{0.1+1}$ ;  $120_{0.4+1}$ ;  $120_{0.9+1}$ ) between 0.2 and 3Gy with Allura Xper FD20 system (Philips, Amsterdam, Netherland). Six calibration curves were constructed (CC- $70_{0.1+1}$  to CC- $120_{0.9+1}$ ). Films reading were carried out with a commercial scanner (Epson, Suwa, Japan). Each beam quality was characterized in terms of mean energy (ME) in air, with table, with  
35 table and water phantom using Monte Carlo (MC) simulations. The influence of kVp and additional filtration selection on PSD measurement was evaluated free-in-air with a cross reading of each films with each CC. As several kVp and additional filtrations could be used during a procedure, additional films were exposed in air with mixed kVp ( $\{70_{1/3}+90_{1/3}+120_{1/3}\}_{0.1+1}$  and  $\{70_{1/3}+90_{1/3}+120_{1/3}\}_{0.4+1}$ ) and with mixed additional filtration  
40 ( $\{70_{0.1+1}\}_{1/2}+\{70_{0.4+1}\}_{1/2}$  to  $\{120_{0.1+1}\}_{1/2}+\{120_{0.4+1}\}_{1/2}$ ). Beam qualities of the mixed beams were also characterized in terms of ME with the MC simulations. The influence of clinical mixed kVp and additional filtration on PSD measurement was again evaluated free-in-air with a cross reading of each mixed beam films with each CC. Finally, a cohort of 155 patient films from cardiology (37) and vascular (118) procedures were read with each CC. Routine  
45 calibration beam quality  $120_{0.1+1}$  was taken as reference ( $Dose_{\text{Norm}}$ ). Statistical comparisons between reference calibration beam quality and other beam qualities was obtained using the paired MannWhitney-Wilcoxon test.

## Results:

ME ranged from 45.6keV to 75.5keV for 70<sub>0.1+1</sub> to 120<sub>0.9+1</sub> beam qualities in air. Mixed beam  
50 ME ranged from 48.3keV to 65.3keV in air. Table transmission and patient backscatter  
decreased ME up to 4.9keV for 120<sub>0.9+1</sub> beam quality. In terms of beam reading in air, the  
read dose was overestimated when the ME of the film was greater than the ME of the CC  
used and vice versa. Deviations ranged from -28% (70<sub>0.1+1</sub> read with CC-120<sub>0.9+1</sub>) to +41%  
(120<sub>0.9+1</sub> read with CC-70<sub>0.1+1</sub>). For mixed beam, when the exposed film was read with the  
55 closest ME calibration the maximum deviation was -12% (ME 53keV film read with CC-  
90<sub>0.4+1</sub>/59.4keV). The error ranged from -24% (ME 48.1keV read with CC-120<sub>0.9+1</sub>) to +28%  
(ME 64.9keV film read with CC-70<sub>0.1+1</sub>). Dose reading variations were equivalent for cardiac  
and vascular patients depending on CC. Dose ratio with Dose<sub>Norm</sub> ranged from -12% (CC-  
120<sub>0.9+1</sub>) to +25% (CC-70<sub>0.1+1</sub>). PSD tended to be underestimated when the CC used had a  
60 higher ME than the reference and vice versa.

**Conclusions:** Overall we observed that for a wider ME difference between the exposed film  
and the CC used, a larger deviation was observed. The choice of beam quality for the  
calibration is a key point when additional filtration and kVp are automatically controlled in  
clinical conditions.

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**KEY WORDS:** Radiochromic film, calibration, energy dependence, Interventional  
angiography, patients.

## ABBREVIATIONS

70 CC: Calibration curves

KA<sub>ref</sub>: Reference Air Kerma

MC: Monte Carlo

ME: Mean Energy

$P_{KA}$  : Air Kerma Product

75 PSD: Peak Skin Dose

## INTRODUCTION

X-ray image guided procedures are widely used for diagnostic and therapeutic examinations. Interventional angiography can deliver high dose to skin<sup>1</sup> and skin injuries have been reported<sup>2, 3</sup>. Hence, radiation dose management guidelines have been proposed to improve patient follow-up<sup>4</sup>. Skin injuries are directly related to the peak skin dose (PSD). Patients should have clinical follow-up above a PSD of 3 Gy. Such a follow-up is improved by having both the PSD and extent(s) of skin dose greater than 3 Gy, with a skin dose map. Though, dose metrics such as the reference point air kerma ( $KA_{ref}$ ) and the kerma area product ( $P_{KA}$ ) are useful indicators, they are poorly correlated to the PSD<sup>5</sup> and they do not give any dose extent information. Thus, several methods have been proposed to monitor skin dose<sup>6</sup>. Non real-time dosimeters, such as TLD chip or polymer gel can be placed in the patient back prior to the procedure<sup>5-7</sup>. PSD can also be calculated from indirect dose metrics, such as the  $KA_{ref}$  or the  $P_{KA}$ <sup>8-10</sup>. On-line tools have been developed to monitor PSD and give a skin dose map for radiation risk management during interventions<sup>11, 12</sup>. Direct measurements of PSD can be performed using Gafchromic® films XR-RV3<sup>5, 6, 12-16</sup>. The high resolution and the large surface of the film results in a 2D dose map. A film calibration is required to evaluate PSD<sup>16</sup> and is performed in the air, and the kVp dependence of film response has been previously investigated<sup>16</sup>. However additional filtration was introduced to reduce the amount of low energy photon<sup>17</sup>. Both kVp and total filtration modify the photon spectrum, a recent study showed the importance of choosing the appropriate calibration beam quality in air<sup>18</sup>. Hence, patient follow up depends on the beam quality chosen for the film calibration (energy and filtration). To our knowledge, although numerous calibration studies were performed for previous XR films<sup>19-22</sup>, only two studies were conducted for XR-RV3 characterization films<sup>16, 18</sup>. This study examines for the first time the impact of XR-RV3 calibration on clinical PSD reading and dose map by extension.

Since interventional imaging systems regulates kVp and additional filtration, response of XR-  
RV3 film has been investigated. We have constructed six calibration curves. Cross readings  
105 between each exposed beam quality films with each free-in-air calibration are reported. As  
several beam qualities could be selected by the system dose rate control during a procedure,  
we analyzed the film response exposed to mixed beam qualities using our six calibration  
curves. The influence of table transmission and patient backscattered photons were also  
investigated by calculating beam Mean Energy (ME) in air, using Monte Carlo (MC)  
110 simulations. Finally, calibration conditions on clinical dose readings were investigated in a  
cohort of 155 patient procedures.

## **METHODS AND MATERIAL**

### **X ray source**

The reflective-type XR-RV3 Gafchromic® films (International Specialty Products (ISP),  
115 Wayne, USA) were irradiated in interventional radiology equipment: Allura Xper FD 20  
(Philips, Amsterdam, Netherland). The X-ray system has a built-in filtration of 2.5 mm Al  
and different additional filtrations are available depending on the selected protocol. In this  
study, the films were exposed in fluoroscopy mode with a pulsed beam of 15 frames per  
second. An additional filtration of 0.9 mmCu + 1 mmAl was set by choosing the low dose  
120 fluoroscopy mode. The medium dose fluoroscopy and the high dose fluoroscopy mode were  
chosen respectively to select 0.4 mmCu+ 1 mmAl and 0.1 mmCu+ 1 mmAl .The highest dose  
rate was reached by positioning lead aprons on the table at a fixed tube potential (kVp) and  
constant additional filtration.

### **125 Monte Carlo Simulation**

X-ray tube modeling has been introduced in PENELOPE Monte-Carlo code <sup>24</sup>. In clinical  
measurements, the beam can cross the table and pad, and is exposed to backscattered photons  
coming from the patient. In our simulation, photon spectra have been simulated in air. Spectra  
130 were recorded at 70 cm from the source for 3 setups in air: without table and pad, with table  
and pad, with table and pad and cylindrical water phantom. We calculated beam mean  
energies (ME) for each set-up:  $ME_{air}$ ,  $ME_{air-table}$ ,  $ME_{air-table-water}$  for each combination of three  
kVps (70, 90, and 120) and additional filtration detailed in X ray source section. Figure 1  
summarizes simulation configurations.

135 Table and pad were assimilated to carbon fiber to reproduce table transmission. The elliptical  
water phantom was 24 cm thick and 52 cm width (170 cm long).

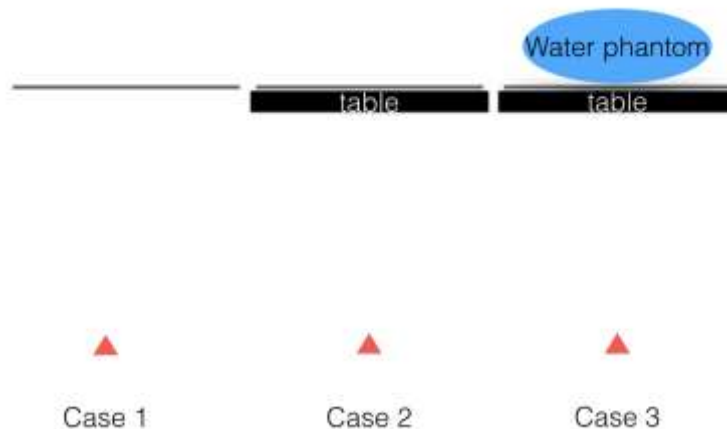


Figure 1: Photon spectrum simulations in PENELOPE. The source is represented by a red triangle. Case 1: spectra free-in-air. Case 2: spectra after table and pad. Case 3: spectra between patients couch and water phantom.

#### 140 Free-in-air calibration

Film calibrations were carried out in free-in-air, films were placed on a six cm-thick polystyrene support providing negligible backscatter and irradiated at 37 cm from the focal spot. A flat ionization chamber 10x6-60 (Radcal, Monrovia, USA), was positioned at 1.5 cm above the films. Therefore, the inverse square law was applied to correct dose measurements.

145 In order to have the totality of the ionization chamber in the exposure field, a diagonal of 48 cm without zoom was used. Films were cut into pieces of 7 x 8 cm, white side facing source.

Six calibration curves were constructed corresponding to different beam qualities, with different additional filtrations and kVp (Table 1). For each beam quality, calibrations were carried out using seven points (0; 0.2; 0.5; 1; 1.5; 2; 3 Gy). Half value layers (HVL) were

150 measured with RaySafe Xi R/F detector (Unfors RaySafe, Billdal, Sweden).



**Table 1: Beam quality and free-in-air calibration conditions used in this study**

Combinations	kVp	Additional filtration	Half value layer (mm)	Dose rate (Gy/min)	Calibration duration (min)
70 <sub>0,1+1</sub>	70	0.1 mm Cu + 1 mm Al	4.29	0.070	118
90 <sub>0,1+1</sub>	90	0.1 mm Cu + 1 mm Al	5.37	0.223	37
90 <sub>0,4+1</sub>	90	0.4 mm Cu + 1 mm Al	7.79	0.113	73
120 <sub>0,1+1</sub>	120	0.1 mm Cu + 1 mm Al	7.03	0.222	37
120 <sub>0,4+1</sub>	120	0.4 mm Cu + 1 mm Al	9.24	0.111	72
120 <sub>0,9+1</sub>	120	0.9 mm Cu + 1 mm Al	11.40	0.114	74

### Film scanning and analysis

160 For each beam quality, the exposed films were scanned at one week  $\pm$  1h post exposure, with an Epson 10000 Expression XL as per ISP recommendations. The software package « Epson Scan » (Version 3.49F) was used to control the scan parameters, which included scanning in “Professional Mode”, reflective mode, without color corrections and with a resolution of 72 dpi.

165 Each calibration film section was placed orange-side down in the center of the scanner in the most uniform area.

The film images were analyzed with the software Film Qa-XR (ISP, Wayne, USA). A rectangular region of interest (ROI), approximately 2 x 2 cm, was placed in the center of each film image. Taking into account ISP recommendations the red color channel was used. The  
170 mean measured reflective density was associated to the measured dose.

On each patient film, a square ROI of 1 cm<sup>2</sup> was positioned manually in the region of maximum dose. The mean dose in this ROI is the PSD. ROIs were positioned by an

experienced medical physicist (JG) with five years of experience with Gafchromic® XR-RV3 films.

#### 175 **Dose cross - readings in air**

Each free-in-air exposed films were read with each CC. This cross reading was compared to the actual measured dose. Mean discrepancies above all dose levels were evaluated for each beam quality read.

In clinical condition, additional filtration and kVp may vary depending on the patient, the X-ray tube angulation or procedure. To evaluate the influence on the film of a variation of the  
180 additional filtration or kVp during an examination, we exposed the films to different conditions.

We studied the additional filtration change during an examination with exposed films to 70, 90 and 120 kVp at the dose levels of 0.4, 0.8 to 1.2 Gy . For each level, 50% of the dose has  
185 been delivered with an additional filtration of 0.1 mm Cu and 50% with 0.4 mm Cu ( $\{70_{0.1+1}\}_{1/2} + \{70_{0.4+1}\}_{1/2}$  to  $\{120_{0.1+1}\}_{1/2} + \{120_{0.4+1}\}_{1/2}$ ).

We studied the change in kVp during an examination with exposed films at 0.1 and 0.4 for three dose levels of 0.6; 1.2 and 1.8 Gy respectively. Each dose level was equally exposed to 70, 90 and 120 kVp ( $\{70_{1/3} + 90_{1/3} + 120_{1/3}\}_{0.1+1}$  and  $\{70_{1/3} + 90_{1/3} + 120_{1/3}\}_{0.4+1}$ ).

#### 190 **Patient**

This study was conducted at the Radiology Dept. of Nimes University Hospital from May 2013 to June 2013. Reflective-type XR-RV3 Gafchromic® films were positioned in the patient back and PSD were measured for 155 patients who were admitted for a coronary chronic total occlusion (CTO) or for an abdominal embolization. Angioplasty stentings (AS)  
195 for CTO were performed in an interventional radiology room Allura Xper FD10 (Philips, Amsterdam, Netherland) and abdominal embolization in Allura Xper FD20 (Philips, Amsterdam, Netherland).

Each film was read using all CC ( $70_{0.1+1}$ ;  $90_{0.1+1}$ ;  $90_{0.4+1}$ ;  $120_{0.1+1}$ ;  $120_{0.4+1}$ ;  $120_{0.9+1}$ ). Thirty-seven AS and 118 abdominal embolization (22 gonadal-vein, 23 digestive-artery, 17 renal-artery, 10 iliac-artery, 15 uterine-artery, 11 hepatic chimio-embolization and 20 others location embolization) were performed (Table 2).

**Table 2: Patient population for the period May 2013 to June 2015**

	Cardiology	Vascular
Number	37	118
Sex	10 females and 27 males	47 females and 71 males
Age	65.8 (42;89)	59.6 (16; 91)
Weight	76.4 (63; 106)	76.6 (65; 83)
Height	169.5 (160; 180)	170.2 (164; 176)

The mean PSD value and standard deviation of the ROI were measured for each CC. The read doses by each CC were normalized to the reference beam quality routinely used:  $120_{0.1+1}$ .

Measured doses were normalized ( $Dose_{Norm}$ ) to the reference beam quality used routinely:  $120_{0.1+1}$ .

Finally, in clinical practice, PSD threshold can be used to trigger patient follow-up for doses that might produce relevant injury in a normal size patient. Therefore, we have counted the number of patient above 3Gy as recommended by the SIR guidelines<sup>4</sup>, with each CC.

### Statistics

Statistical analysis was performed using ‘Biostatgv’ (<http://marne.u707.jussieu.fr/biostatgv>). The comparison between the reference beam quality routinely used and other beam quality

was obtained using the paired MannWhitney-Wilcoxon test. A P-value  $< 0.01$  (adjusted for multiple comparisons) was considered significant.

Monte Carlo Simulation

Figure 2 shows the influence of the filtration (2.a) and voltage (2.b) on the air photon spectra.

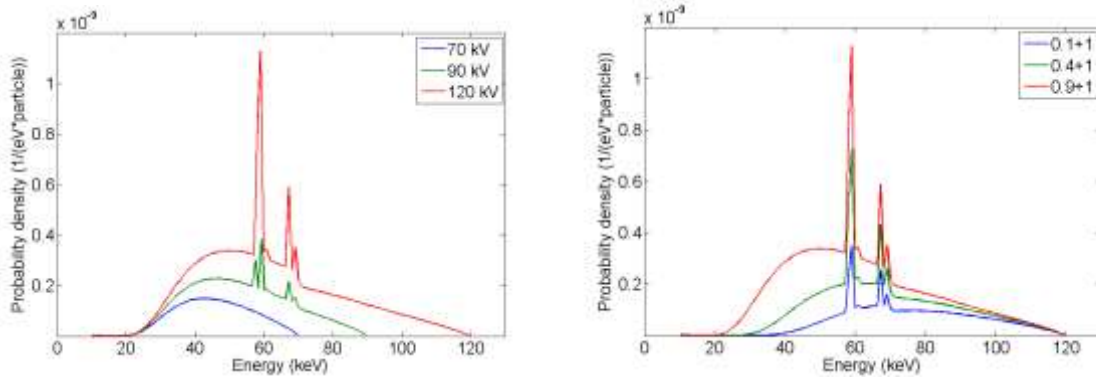
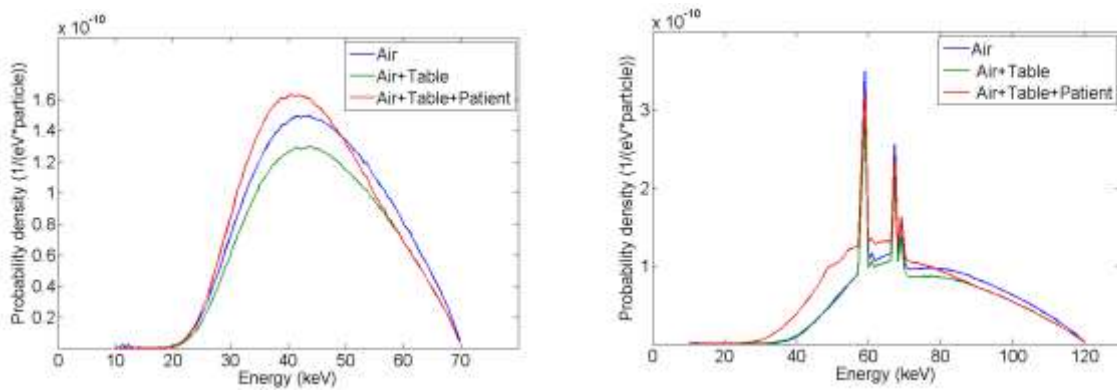


Figure 2: Air photon spectrum. Left: 0.1 mm Cu, 70/ 90/ 120 kVp. Right: 120 kVp, 0.1/ 0.4/0.9 Cu +1 mm Al

Figure 3 compares 6 MC-simulated spectra for 70<sub>0,1+1</sub> beam and for 120<sub>0,9+1</sub> beam: in air, in air with table, in air with table and at water phantom entrance.



225 Figure 3: Air photon spectrum. Left:70<sub>0,1+1</sub> Right: 120<sub>0,9+1</sub> in Air/Air+Table/Air+Table+patient

$ME_{air}$ ,  $ME_{air-table}$ ,  $ME_{air-table-water}$  are listed in Table 3 for each studied beam. The table reduces the amount of photon. However, the ME is only slightly affected (less than 1 keV). The presence of backscattered photons results in a decrease of the ME. The highest decrease of 4.9 keV is observed for the highest beam quality (120<sub>0,9+1</sub>). Our results show that for a higher  $ME_{air}$ , more pronounced decrease of  $ME_{Air-Table-Water}$  is observed.

**Table 3: Mean keV in air, with table pad, with table and water phantom.  $\Delta$ keV corresponds to the difference between mean energy in air and other simulations.**

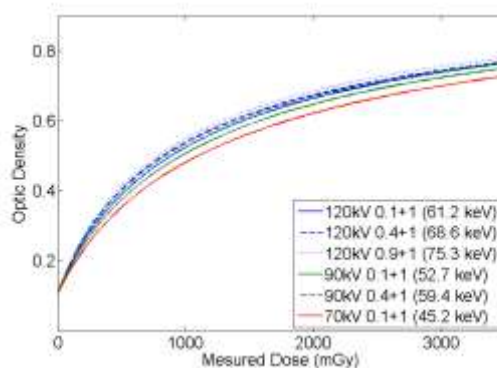
Combinations	$ME_{Air}$	$ME_{Air-Table}$	$\Delta$ keV	$ME_{Air-Table-Water}$	$\Delta$ keV
	(keV)	(keV)	(Air/Air-Table)	(keV)	(Air/Air-Table-Water)
70 <sub>0,1+1</sub>	45.6	45.7	-0.1	44.5	-1.1
90 <sub>0,1+1</sub>	53.0	53.0	0.0	51.3	-1.7
90 <sub>0,4+1</sub>	59.4	59.1	0.3	56.6	-2.8
120 <sub>0,1+1</sub>	61.7	61.6	0.1	59.0	-2.7
120 <sub>0,4+1</sub>	68.8	68.5	0.3	65.0	-3.8
120 <sub>0,9+1</sub>	75.5	74.9	0.6	70.6	-4.9

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### Free-in-air calibration

Each « free-in-air » calibration took less than two hours depending on the combination kVp/Filtration (Table 1). The fastest calibration (37 min) was obtained with a dose rate of 0.222 Gy/min for 90<sub>0,1+1</sub> and 120<sub>0,1+1</sub> beam. The slowest calibration (118 min) was obtained with a dose rate of 0.070 Gy/min for 70<sub>0,1+1</sub> beam.

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**Figure 4: Calibration curves for each beam quality**

Figure 4 shows the CC obtained for the various beam qualities. For the same dose, the measured optical density decreased with the reduction of the ME of the beam.

## 245 Dose cross- readings in air

The average difference between the read and measured dose in air was 1 to 2% when exposed films were read with the associated CC. The read dose was overestimated when the ME of the film was greater than the ME of the CC used and vice versa (Figure 5.a). For example, when the 120<sub>0,9+1</sub> films (ME of 75.3 keV) were read with the 70<sub>0,1+1</sub> CC (ME of 45.2 keV) the measured dose was overestimated by 41%. Conversely, the read dose was underestimated by 28% when the 70<sub>0,1+1</sub> films are read with 120<sub>0,9+1</sub> CC.

Figure 5b shows the reading variations of mixed films using different CC. The maximum deviation was -12 % if the exposed film was read with the two CC closest in terms of ME. A general trend was observed: for a wider ME difference between the exposed film and the CC used, a larger deviation was observed.

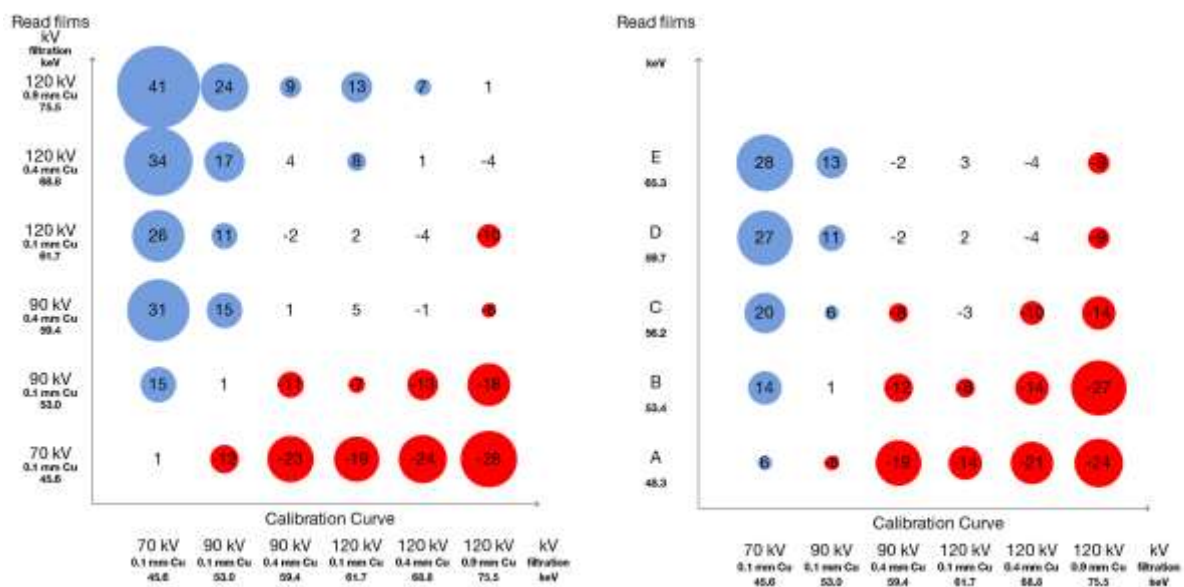


Figure 5: Mean reading deviations (in percentage) in air. Left (5.a): Cross reading between the 6 calibration curves Right (5.b): reading of mixed quality beam with 6 calibration curves.

### Patient's film reading

260 Dose reading variations are equivalent for cardiac and vascular patients depending on CC  
 (Tables 4 and 5). The measured dose was overestimated when films were read with a CC with  
 a lower voltage than the reference voltage for the same additional filtration. At 90 kVp and 70  
 kVp, the skin dose was overestimated by 10% and 25%, respectively. Conversely, exposed  
 films read using a CC with a higher filtration than the reference voltage for the same filtering  
 265 the measured dose was underestimated. Skin doses were underestimated by -7% and -12% for  
 120<sub>0,4+1</sub> and 120<sub>0,9+1</sub>, respectively. A general trend was observed: PSD tends to be  
 underestimated when the CC used has a higher ME than the reference and vice versa, except  
 for 90<sub>0,4+1</sub> beam quality.

**Table 4: Cardiology PSD reading**

Combinations	Energy	PSD (mGy)		Dose <sub>Norm</sub>		p-value
	(keV)	Mean (min.max)				
70 <sub>0,1+1</sub>	45.2	645.6	(45.0 ; 4335.3)	24.0%	± 0.3%	p: < 0.01
90 <sub>0,1+1</sub>	52.7	569.9	(39.9 ; 3766.8)	9.2%	± 0.5%	p: < 0.01
90 <sub>0,4+1</sub>	59.4	489.5	(33.3 ; 3453.7)	-5.1%	± 1.2%	p: < 0.01
<b>120<sub>0,1+1</sub></b>	<b>61.2</b>	<b>518.6</b>	<b>(34.9 ; 3456.4)</b>	-	± -	-
120 <sub>0,4+1</sub>	68.6	482.3	(34.0 ; 3383.6)	-7.1%	± 1.0%	p: < 0.01
120 <sub>0,9+1</sub>	75.3	457.9	(31.0 ; 3133.6)	-11.5%	± 0.5%	p: < 0.01

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**Table 5: Vascular PSD reading**

Combinations	Energy	PSD (mGy)		Dose <sub>Norm</sub>		p-value
	(keV)	Mean (min.max)				
70 <sub>0.1+1</sub>	45.2	1237.1	(166.1 ; 2555.7)	24.5%	± 1.1%	p: < 0.01
90 <sub>0.1+1</sub>	52.7	1089.4	(146.9 ; 2239.6)	9.9%	± 1.2%	p: < 0.01
90 <sub>0.4+1</sub>	59.4	946.8	(125.3 ; 1996.7)	-5.6%	± 1.1%	p: < 0.01
<b>120<sub>0.1+1</sub></b>	<b>61.2</b>	<b>997.7</b>	<b>(133.4 ; 2056.7)</b>	-	± -	-
120 <sub>0.4+1</sub>	68.6	926.8	(123.6 ; 1951.3)	-7.0%	± 1.4%	p: < 0.01
120 <sub>0.9+1</sub>	75.3	882.9	(117.5 ; 1839.6)	-11.7%	± 0.5%	p: < 0.01

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Out of the 155 patients included in this study (admitted for AS and abdominal embolization since May 2013), only one patient was triggered for a follow-up using calibration routine CC (120<sub>0.1+1</sub>) with a 3 Gy PSD threshold. The number of patients followed would have reached six patients using 70<sub>0.1+1</sub> CC and would have been zero using 120<sub>0.9+1</sub> CC.

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## DISCUSSION

285 The reflective-type XR-RV3 Gafchromic® films have many advantages and represent the most effective and most appropriate solution to estimate and locate PSD during interventional radiology procedure. These films have a large size and a high spatial resolution and are simpler to use than other routinely detectors (TLDs or diodes). However, PSD reading is carried out in deferred time. Indeed, the films are read 24 hours after exposure, and a CC has  
290 to be assigned to correlate the measured optical density to the delivered dose. Film calibration is a critical step to ensure a reliable PSD measurement. Calibration is mostly performed according to the manufacturer's recommendations, in air, with the higher dose rate ( $>1$  Gy/min). However, according to Farah et al<sup>18</sup>, dose rate variation does not have influence on film calibration.

295 Our study was performed with films white facing towards x-ray source, following ISP recommendation. However, as some groups work using the other side facing the source, it would be interesting to evaluate the orange side facing source<sup>18</sup>. We used our flatbed scanner without uniformity correction. Hence, our scanner related uncertainty is up to 7% ( $k=1$ ). However, we used the same scanner and read all films with the same procedure, our mean  
300 deviation was not affected by the film reading procedure.

Film calibration in air does not consider patient backscattered photons nor table attenuation. MC simulations were conducted to quantify the impact of these two factors on film calibration in terms of beam ME. The results of these simulations showed that the impact on the beam ME is relatively low taking into account the attenuation of the table ( $-0.3\% \pm 0.3\%$ )  
305 and slightly more important with the backscattered issued by the water phantom ( $-4.4\% \pm 1.3\%$ ). In both cases, the reduction of the ME tended to increase when beam energy increases. Our simulation results are in agreement with the MC simulation conducted by McCabe et

al.<sup>14</sup>. Indeed, the ME was reduced by 3.4 keV for 120 kVp with a first HVL of 6.96 mm Al and a ME of 49.9 keV.

310 To obtain a high dose rate, film calibration is usually performed in service mode with the highest voltage and the lowest additional filtration, corresponding to 120<sub>0.1+1</sub>. With the energy dependence of the films<sup>14</sup>, the measured doses may be over- or under-estimated in function of the beam quality used during clinical procedure. To clinically evaluate this energy dependence, five calibration energies different from the energy typically used in calibration  
315 routine (120<sub>0.1+1</sub>) were studied and compared. Our results confirm that dose measurements with Gafchromic® films are dependent on the beam energy and in particular to kVp and filtration variations. McCabe et al.<sup>14</sup> showed that for the same filtration, 500cGy to 100kV gave 670cGy (+ 34%) at 80 kVp and t 420cGy (-16%) at 120kV. The same trend was found in this study in air. With the same additional filtration, for 200cGy measured at 90<sub>0.1+1</sub>, the  
320 measured dose is increased by +14% (228cGy) at 70<sub>0.1+1</sub> and decreased -11% (178cGy) at 120<sub>0.1+1</sub>. Furthermore, our study also evaluated the filtration influence on the measured dose. For 120<sub>0.4+1</sub> exposed films, the measured dose is underestimated by -4% with 120<sub>0.9+1</sub> CC and overestimated by +8% with 120<sub>0.1+1</sub> CC.

325 **CONCLUSION**

In the air, discrepancies between read and measured dose may even reach -28% and +41%. It is observed that the more the ME of the beam increases, relative to the ME of the CC, the more the measured dose is overestimated and vice versa.

During an interventional radiology procedure, the use of fluoroscopy and digital acquisition  
330 modes results in different kVp/filtration selection. Moreover, this combination depends on the patient's morphology, the procedure, and the incidence used. As found by McCabe et al.<sup>14</sup>, limitation to a single calibration energy for PSD reading leads to an error in the measurement of the dose to the skin. PSD measured doses on patients for cardiology and vascular procedures confirmed these results. Similar differences are found for both types of  
335 procedures. Discrepancies between -12% and +25% were found between our reference CC and 5 other calibration energies. For one CTO, a PSD of 346 cGy was measured with reference CC but PSD ranged from 314cGy to 434cGy with the other CC. Observed discrepancies in air are larger than for PSD measured discrepancies. This can be correlated to the range of ME in air and with water phantom. The range of ME CC is reduced by the  
340 contribution of backscattered photons.

The beam quality choice for the calibration is a key point to establish reliable patient follow-up when additional filtration and kVp are automatically controlled. In clinical practice, film calibration should be performed after analyzing kVp and filtration used for the target procedure. A CC can also be defined based on the specialty studied (vascular, cardiovascular  
345 ...) according to the variations of the parameters used in the X-ray system selected protocols. In all cases, if single CC is constructed, the results of this study can be used to provide an estimate of the error associated with the beam quality dependence.

This study provides an estimate of the error depending on the voltage and filtration used in clinical conditions for two specialties studied.

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355 **REFERENCES**

- <sup>1</sup> T.R. Koenig, D. Wolff, F.A. Mettler, L.K. Wagner, "Skin injuries from fluoroscopically guided procedures: part 1, characteristics of radiation injury," *AJR. American journal of roentgenology* **177**, 3-11 (2001).
- <sup>2</sup> D.L. Miller, S. Balter, P.E. Cole, H.T. Lu, B.A. Schueler, M. Geisinger, A. Berenstein, R. Albert, J.D. Georgia, P.T. Noonan, J.F. Cardella, J. St George, E.J. Russell, T.W. Malisch, R.L. Vogelzang, G.L. Miller, 3rd, J. Anderson, R.-I. study, "Radiation doses in interventional radiology procedures: the RAD-IR study: part I: overall measures of dose," *Journal of vascular and interventional radiology : JVIR* **14**, 711-727 (2003).
- 360 <sup>3</sup> S. Balter, J.W. Hopewell, D.L. Miller, L.K. Wagner, M.J. Zelefsky, "Fluoroscopically guided interventional procedures: a review of radiation effects on patients' skin and hair," *Radiology* **254**, 326-341 (2010).
- <sup>4</sup> M.S. Stecker, S. Balter, R.B. Towbin, D.L. Miller, E. Vano, G. Bartal, J.F. Angle, C.P. Chao, A.M. Cohen, R.G. Dixon, K. Gross, G.G. Hartnell, B. Schueler, J.D. Statler, T. de Baere, J.F. Cardella, S.I.R. Safety, C. Health, C.S.o.P. Committee, "Guidelines for patient radiation dose management," *Journal of vascular and interventional radiology : JVIR* **20**, S263-273 (2009).
- 370 <sup>5</sup> J. Farah, A. Trianni, E. Carinou, O. Ciraj-Bjelac, I. Clairand, J. Dabin, C. De Angelis, J. Domienik, H. Jarvinen, R. Kopec, M. Majer, F. Malchair, A. Negri, L. Novak, T. Siiskonen, F. Vanhavere, Z. Knezevic, "Measurement of maximum skin dose in interventional radiology and cardiology and challenges in the set-up of European alert thresholds," *Radiation protection dosimetry* **164**, 138-142 (2015).
- 375 <sup>6</sup> S. Balter, "Methods for measuring fluoroscopic skin dose," *Pediatric radiology* **36 Suppl 2**, 136-140 (2006).
- <sup>7</sup> P.E. Antoniou, P. Bousbouras, R. Sandaltzopoulos, E. Kaldoudi, "Investigating the potential of polymer gel dosimetry for interventional radiology: first results," *Physics in medicine and biology* **53**, N127-136 (2008).
- 380 <sup>8</sup> A.K. Jones, A.S. Pasciak, "Calculating the peak skin dose resulting from fluoroscopically guided interventions. Part I: Methods," *Journal of applied clinical medical physics / American College of Medical Physics* **12**, 3670 (2011).

- 9 A.K. Jones, J.E. Ensor, A.S. Pasciak, "How accurately can the peak skin dose in fluoroscopy be  
385 determined using indirect dose metrics?," *Medical physics* **41**, 071913 (2014).
- 10 Y. Khodadadegan, M. Zhang, W. Pavlicek, R.G. Paden, B. Chong, E.A. Huettl, B.A. Schueler, K.A.  
Fetterly, S.G. Langer, T. Wu, "Validation and initial clinical use of automatic peak skin dose  
localization with fluoroscopic and interventional procedures," *Radiology* **266**, 246-255 (2013).
- 11 V.K. Rana, S. Rudin, D.R. Bednarek, "Updates in the real-time Dose Tracking System (DTS) to  
390 improve the accuracy in calculating the radiation dose to the patients skin during fluoroscopic  
procedures," *Proceedings of SPIE--the International Society for Optical Engineering* **8668**, 86683Z  
(2013).
- 12 C. Bordier, R. Klausz, L. Desponds, "Accuracy of a dose map method assessed in clinical and  
anthropomorphic phantom situations using Gafchromic films," *Radiation protection dosimetry* **165**,  
395 244-249 (2015).
- 13 C. Bordier, R. Klausz, L. Desponds, "Patient dose map indications on interventional X-ray systems and  
validation with Gafchromic XR-RV3 film," *Radiation protection dosimetry* **163**, 306-318 (2015).
- 14 B.P. McCabe, M.A. Speidel, T.L. Pike, M.S. Van Lysel, "Calibration of GafChromic XR-RV3  
radiochromic film for skin dose measurement using standardized x-ray spectra and a commercial  
400 flatbed scanner," *Medical physics* **38**, 1919-1930 (2011).
- 15 N. Khelassi-Toutaoui, A. Toutaoui, A. Merad, Z. Sakhri-Brahimi, B. Baggoura, B. Mansouri,  
"Assessment of Radiation Protection of Patients and Staff in Interventional Procedures in Four Algerian  
Hospitals," *Radiation protection dosimetry* 2015).
- 16 J.G. M. Labattu, V. Chassin, L. Cassagnes, F. Magnier, D. Donnarieix, L. Boyer, L. Chabrot,  
405 "Assessment of skin dose in interventional radiology using radiochromic films," *Radioprotection* **48**,  
115-126 (2013).
- 17 K.A. Fetterly, "Investigation of the practical aspects of an additional 0.1 mm copper x-ray spectral filter  
for cine acquisition mode imaging in a clinical care setting," *Health physics* **99**, 624-630 (2010).
- 18 J. Farah, A. Trianni, O. Ciraj-Bjelac, I. Clairand, C. De Angelis, S. Delle Canne, L. Hadid, C. Huet, H.  
410 Jarvinen, A. Negri, L. Novak, M. Pinto, T. Siiskonen, M.J. Waryn, Z. Knezevic, "Characterization of  
XR-RV3 GafChromic((R)) films in standard laboratory and in clinical conditions and means to evaluate  
uncertainties and reduce errors," *Medical physics* **42**, 4211-4226 (2015).

- 19 R. Sanchez, E. Vano, J.M. Fernandez, A. Machado, N. Roas, "Visual and numerical methods to  
measure patient skin doses in interventional procedures using radiochromic XR-RV2 films," Radiation  
415 protection dosimetry **147**, 94-98 (2011).
- 20 A. Blair, J. Meyer, "Characteristics of Gafchromic XR-RV2 radiochromic film," Medical physics **36**,  
3050-3058 (2009).
- 21 S.A. Dini, R.A. Koon, J.R. Ashburn, A.S. Meigoonia, "Dosimetric evaluation of GAFCHROMIC XR  
type T and XR type R films," Journal of applied clinical medical physics / American College of  
420 Medical Physics **6**, 114-134 (2005).
- 22 O. Rampado, E. Garelli, S. Deagostini, R. Ropolo, "Dose and energy dependence of response of  
Gafchromic XR-QA film for kilovoltage x-ray beams," Physics in medicine and biology **51**, 2871-2881  
(2006).