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Original paper

Feasibility of setting up generic alert levels for maximum skin dose in fluoroscopically guided procedures

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A R T I C L E I N F O

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A B S T R A C T

Purpose: The feasibility of setting-up generic, hospital-independent dose alert levels to initiate vigilance on possible skin injuries in interventional procedures was studied for three high-dose procedures (chemoembolization (TACE) of the liver, neuro-embolization (NE) and percutaneous coronary intervention (PCI)) in 9 European countries.
Methods: Gafchromic® films and thermoluminescent dosimeters (TLD) were used to determine the Maximum Skin Dose (MSD). Correlation of the online dose indicators (fluoroscopy time, kerma- or dose-area product (KAP or DAP) and cumulative air kerma at interventional reference point ($K_{a,r}$)) with MSD was evaluated and used to establish the alert levels corresponding to a MSD of 2 Gy and 5 Gy. The uncertainties of alert levels in terms of DAP and $K_{a,r}$, and uncertainty of MSD were calculated.
Results: About 20–30% of all MSD values exceeded 2 Gy while only 2–6% exceeded 5 Gy. The correlations suggest that both DAP and $K_{a,r}$ can be used as a dose indicator for alert levels (Pearson correlation coefficient p mostly > 0.8), while fluoroscopy time is not suitable (p mostly < 0.6). Generic alert levels based on DAP (Gy cm^2) were suggested for MSD of both 2 Gy and 5 Gy (for 5 Gy: TACE 750, PCI 250 and NE 400). The suggested levels are close to the lowest values published in several other studies. The uncertainty of the MSD was estimated to be around 10–15% and of hospital-specific skin dose alert levels about 20–30% (with coverage factor k = 1).
Conclusions: The generic alert levels are feasible for some cases but should be used with caution, only as the first approximation, while hospital-specific alert levels are preferred as the final approach.

1. Introduction

In interventional radiology and cardiology, the use of fluoroscopy to guide interventions has strongly improved patient care while simultaneously increasing the risk of skin injuries [1–3]. Therefore, many authors and manufacturers of X-ray equipment have investigated possible

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Table 1
Total number of measurements for all three procedures studied (TACE, PCI, NE).

Country	Method	TACE			PCI			NE			Total		
		DAP	$K_{a,r}$	FT	DAP	$K_{a,r}$	FT	DAP	$K_{a,r}$	FT	DAP	$K_{a,r}$	FT
Belgium	TLD	10	5	8	37	34	37	14	14	14	61	53	59
Croatia	Film				6		6				6	0	6
Finland	Film	8	8	8	7	7	7	14	14	14	29	29	29
France	Film	28	28	28	16	16	14	50	50	50	94	94	92
Greece	Film							12	12	13	12	12	13
Greece	TLD							11	11	11	11	11	11
Italy	Film	32	32	32	8	8	8	12	12	12	52	52	52
Poland	Film				13	13	13	14	14	14	27	27	27
Poland	TLD							12	12	12	12	12	12
Portugal	Film	13		11							13	0	11
Serbia	Film				12	12	12				12	12	12
TOTAL		91	73	87	99	90	97	139	139	140	329	302	324

methods to monitor and reduce patient skin doses during interventional procedures. Accordingly, alert levels (thresholds) have been defined correlating maximum skin dose (MSD) with online dose indicators such as fluoroscopy time (FT), kerma- or dose-area product (KAP or DAP) and cumulative air kerma at interventional reference point ($K_{a,r}$). Such studies in the past have mainly been conducted for interventional cardiology procedures [4,5] usually demonstrating weak correlations between MSD and DAP or $K_{a,r}$.

Recently, software solutions have been developed to show a real-time dose distribution at patient's skin (dose mapping) [6–9]. Software-based dose mapping tools may provide a more user-friendly and accurate setting of alert levels provided they are well validated and benchmarked against measurements. However, this feature is not available in older equipment, and might not even become available in all new equipment, and therefore, the possibility to evaluate the MSD by means of other readily available dose indicators are still of interest.

To measure patient skin doses and quantify exposure, several types of dosimeters have been considered such as scintillation detectors, silicon diodes, MOSFET, thermoluminescent dosimeters (TLD), thermoluminescent (TL) foils, radiochromic films, ionization chambers and gel dosimeters [10–14]. The complexity and heterogeneity of skin exposure in interventional procedures require, however, careful characterization of these detectors. Previous studies [14–18] documented a comprehensive characterization of XR-RV3 GafChromic® films (International Specialty Products) and MCP-N (LiF:Mg, Cu, P) or MTS-N (LiF:Mg, Ti) TLDs and TL foils in laboratory and in clinical conditions. Gafchromic films are associated with relatively large measurement uncertainties, which could exceed 20% (coverage factor k = 1) [15,18]. Meanwhile, TLDs proved to provide slightly better accuracy than films for skin dose measurement with uncertainties within 20% (k = 1) mainly due to their lower energy dependence [17]. However, the use of TLDs or other point detectors involves a high risk of missing the MSD and careful setting of the detectors is required [16]. TL foils seem promising since they combine the good spatial resolution of gafchromic films and the lower energy dependence of TLD.

Accurate evaluation of the MSD with detailed description of its assessment methodology and uncertainties are rarely discussed. Jones et al. [19] studied the accuracy of peak skin dose (PSD) determination in embolization procedures at two sites; they concluded that PSD for such procedures can be determined within ± 35% using indirect dose metrics, but suggested that separate studies are needed for interventional cardiology and neuroradiology procedures. In addition, alert levels are usually reported as site-specific and should be extended to all high dose interventional procedures. To investigate the feasibility of setting up generic, European alert levels, more detailed studies are needed, covering a wide range of hospitals and procedures and with careful evaluation of dosimetry methods used.

In this work, patient skin dose measurements, along with DAP and $K_{a,r}$ recording were performed at different European hospitals for three high dose interventional procedures in radiology and cardiology. The inter-center variability of online dose indicators and their correlation with the MSD were examined. The main objectives were to investigate the feasibility of generic alert levels, compare those to published data and to assess the overall uncertainty in setting up the alert level.

2. Materials and methods

2.1. Clinical procedures and data collection

Patient skin dose measurements were performed at different European hospitals for three typical high dose interventional procedures: chemoembolization of the liver (TACE), neuro-embolization (NE) and percutaneous coronary interventions (PCI). PCI was included because relevant data was easily available from all hospitals and because the focus of this study was to investigate the feasibility of generic alert levels, whereby data from several hospitals was needed. The results are presented and discussed in accordance with the countries involved. The total number of measurements from each country is shown in Table 1. For each individual procedure, the X-ray equipment used and the online dose indicators, namely fluoroscopy time, DAP or $K_{a,r}$ were recorded. Abbreviation "DAP" throughout this paper means the total DAP of the procedure.

Several types of fluoroscopy equipment were included in this study (Table 2). It has been assumed that the selection of tube voltage (kV) and field sizes for the procedures are not affected by the type of equipment and the other equipment-specific characteristics should not affect the correlation between MSD and online dose indicators. For centers where biplane systems were used in NE procedures, participants were requested to provide separate outputs for each tube.

2.2. Maximum skin dose measurement

MSD was determined by two different dosimeters: XR-RV3 GafChromic® films or by using TL pellets and foils as described in detail by Farah et al. [15,20]. Dosimeters were directly set on the patient skin at the entrance of the patient and the TL dosimeters considered to be tissue-equivalent [20,21]. Informed consent was not requested as the patient data was treated anonymously, but patients were informed on the use of the dosimeters according to the local practices of the hospitals.

Calibrations of the dosimeters were performed considering free-in-air irradiations in standard dosimetry laboratory conditions using RQR5 beam quality [22] or corresponding clinical beam quality according to an agreed protocol. During the calibration, the films were set with yellow side facing the X-ray tube. For on patient measurements, films were used in the same way, except in one case (by mistake) when white