The determination of Trigger Levels for patient doses in Interventional Procedures

TRIR project

End report

by

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Introduction

Interventional procedures, by virtue of its low invasiveness, is increasingly used in the treatment of various lesions. The increase in frequency arises from the clear benefit that in many hospitals the interventional procedure is performed in an out-patient setting and replaces a surgical technique which involves treatment as an in-patient and a protracted hospital stay. Despite being less invasive, the interventional procedure does expose patients to a not negligible dose of radiation, because every stage of the intervention is performed under fluoroscopic guidance. Angiographic acquisition from different projections, now also with 3D reformats, are also mandatory. The Euratom 97/43 directive and the implementation into the Belgian legislation introduced the obligation to carry out dosimetric evaluation for "high-dose practices", including interventional radiology procedures.

In literature, different cases are reported for which patients suffered from deterministic skin damage after a complex interventional procedure under guidance of fluroscopy [Shope T, 1996 ; Vano E, 1998 ; Sovik E, 1996 ; Huda W, 1994). Also in Belgium there are some indications [Struelens L et al, 2005] that demonstrate that reaching the limit of deterministic effects to the skin (2 Gy) is realistic for some specific interventional procedures. The international Commission on Radiological Protection [ICRP, 2000] advises that the entrance surface dose (ESD) and its location should be recorded when the maximum cumulative dose is expected to be ≥3Gy (≥1Gy in repeated cases).

An important issue is that the radiologist/cardiologist /gastro-enterologist/ urologist/vascular surgeon/…. is not aware of the doses that are given to the skin of the patients during the procedure. There are a number of practical problems performing patient dosimetry in interventional radiology. The dose-area-product (DAP) has limitations regarding the peak skin dose. In interventional radiology and cardiology the projection direction changes during the procedure and inevitably the area of the skin surface directly irradiated changes. It is also important to consider the back-scatter factor in the evaluation of skin entrance dose. Direct measurements of skin doses with thermoluminescent dosemeters (TLDs) also have limitations, it is difficult to predict before an examination commences, where on the patient's skin the maximum dose will be. Small changes in projection direction can mean a large change in dosemeter reading. This means that a lot of TLDs are needed to be sure to measure the maximum skin dose (MSD) on the patient, which is not possible in routine practice.
A trigger level in terms of a DAP-measurement is much more practical. However, it should be noted, as stated above, that the correlation between the total DAP-value of a procedure and the maximum skin dose

somewhere on the patient is not trivial and depend on the type of procedure.
When such trigger levels are available, the radiologist/cardiologist will be able to follow-up the maximum skin dose to the patient during the procedure and he can be alarmed when the limit for deterministic skin damage is reached.

This project is commissioned by the Federal Agency of Nuclear Control (FANC) and was performed under co-ordination of the Belgian Nuclear Research Centre (SCK•CEN), together with the University Hospital Gasthuisberg Louvain, University of Ghent, Hospital Centre Jolimont-Lobbes and the University Hospital Sart-Tilman Liège.

Method and materials

Overview of procedures

The selection of the interventional procedures in the project was based on literature reviews, the frequency of procedures in Belgium, the known complexity of procedures and after discussion with some interventional radiologists.
The frequency of procedures in Belgium was collected from data received by RIZIV/INAMI (Rijksinstituut voor ziekte- en invaliditeitsverzekering/ Institut National d'Assurance Maladie-Invalidité) from 2005 to 2007. In figure 1, an overview for some interventional procedures is given.

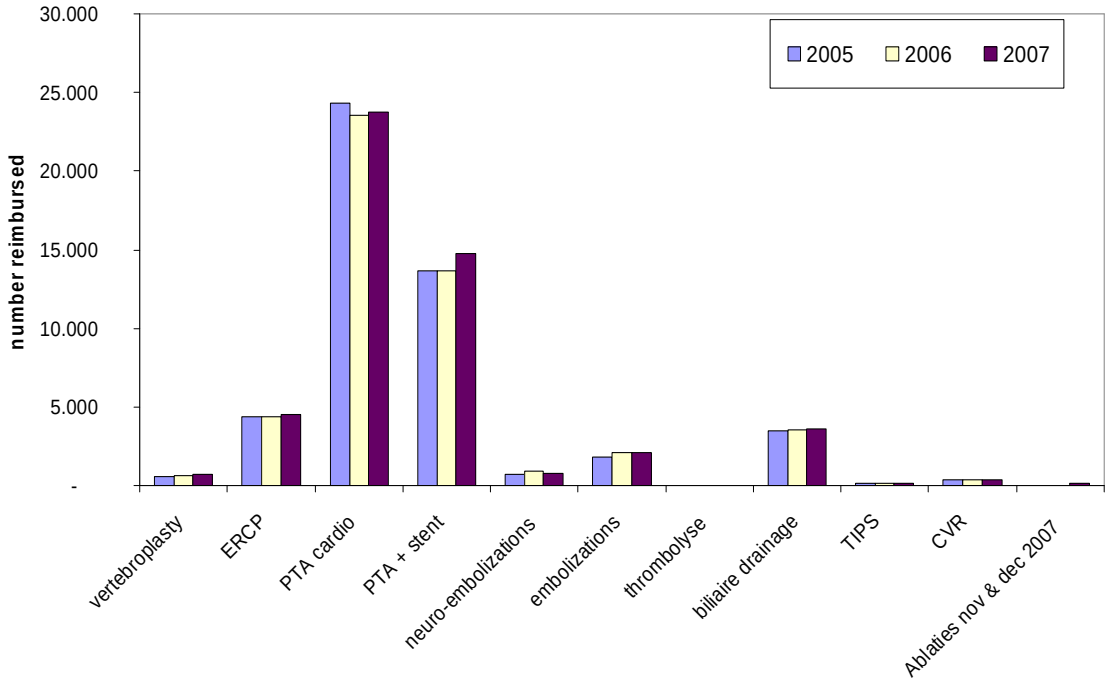


Figure 1: The frequency of some interventional procedures in Belgium from 2005 to 2007.

The most frequently performed interventional procedures are the cardio vascular ones (PTA, PTCA,…). However, maximum skin doses and corresponding trigger levels for these procedures are thoroughly investigated in a previous national project [Bogaert E. *et al*, 2009]
Following procedures were selected for the TRIR project:

- Interventional cardiology:
  - **Radiofrequency (RF) ablations**
    Radiofrequency energy is used to destroy abnormal electrical pathways in heart tissue or normal parts that are contributing to a cardiac disrhythmia. It is used in recurrent atrial flutter, atrial fibrillation, supraventricular tachycardia and some types of ventricular disrhythmia. The energy emitting probe (electrode) is at the tip of a catheter which is placed into the heart, usually through a vein. The practitioner first "maps" an area of the heart to locate the abnormal electrical activity (electrophysiology study) before the responsible tissue is eliminated. RF ablations are performed under image guidance by a cardiac electrophysiologist, a subspecialty of cardiologists.

- Interventional radiology:
  - **Transjugular Intrahepatic Portosystemic Shunt (TIPS)**
    A transjugular intrahepatic portosystemic shunt is an artificial channel in the liver from the portal vein to a hepatic vein. It is created endovascularly (via the blood vessels) via the jugular vein. It is used to treat portal hypertension (which often is due to liver cirrhosis) which frequently leads to intestinal (gastro-oesophageal) bleeding or the buildup of fluid within the abdomen (ascites). TIPS are typically placed by interventional radiologists under fluoroscopic guidance.

  - **Cerebral embolizations**
    Cerebral embolizations consist of interventional work such as coil-embolization of aneurysms and AVM (Arterio-Venous Malformations) gluing. An aneurysm is a localized, blood-filled dilation of a blood vessel caused by disease or weakening of the vessel wall. Minimally-invasive endovascular coiling techniques can be used in the treatment of brain aneurysms. Tiny platinum coils are threaded through the catheter and deployed into the aneurysm, blocking blood flow into the aneurysm and preventing rupture. AVM is an abnormal connection between veins and arteries. The blood supply to the AVM is cut off with coils or particles or glue introduced by a radiographically guided catheter.

  - **Embolizations of the vena spermatica**
    Varicocele is an abnormal enlargement of the vena spermatica. The embolization, performed by an interventional radiologist, involves passing a small wire through a peripheral vein and into the abdominal veins that drain the testes. Through a small flexible catheter, the doctor can obstruct the veins so that the increased pressures from the abdomen are no longer transmitted to the testicles. The testicles then drain through smaller collateral veins.

  - **Chemo-embolizations of the liver**
    Chemo-embolization is a procedure in which the blood supply to a tumor is blocked and anti-cancer drugs are injected directly into the blood vessel feeding a cancerous tumor. In addition, synthetic material, called an

embolic agent, is placed inside the blood vessels that supply blood to the tumor, in effect trapping the chemotherapy in the tumor.

- **Creation or treatment of AV fistula for hemodialysis**
  An arteriovenous fistula is an abnormal, natural or artificial, connection between an artery and a vein. It may be congenital or surgically created for hemodialysis treatments. In dialysis, blood is withdrawn from the vein, purified, and returned to a vein. The volume of blood is too great for veins to handle, so a vein must be arterialized. An artery and vein, usually in the arm above or below the elbow, are sewn together, to create a fistula and arterial pressure enlarges the vein. The enlarged vein can accommodate a cannula or large needle.

- Interventional gastro-enterology procedures
  - **Biliary drainages**
    The most common reason for biliary drainage is blockage to the bile ducts and the bile backs up in the liver. Biliary drainage may also be needed if a hole forms and bile leaks from the duct. This leakage can cause pain and severe infection. Biliary drainage can stop the leaking and help the hole to heal. The biliary drainages can be performed in 2 different ways. There are the conventional procedures where a tube is inserted through the mouth and the oesophagogastric tractus of the patient and the drainage of the bile out of the liver/gall ducts is performed through that pathway. On the other hand, these procedures can also be performed percutaneous by inserting a thin needle through the skin and through the liver into a bile duct. Then dye is injected and the bile duct system is outlined on x-rays. This is called a percutaneous transhepatic cholangiography (PTC). If necessary a thin flexible tube may be inserted to allow the bile to drain.

  - **Endoscopic retrograde cholangiopancreaticography (ERCP)**
    ERCP is a technique that combines the use of endoscopy and fluoroscopy to diagnose and treat certain problems of the biliary or pancreatic ductal systems, including gallstones, inflammatory structures (scars), leaks (from trauma and surgery), and cancer. A flexible camera (endoscope) is inserted through the mouth, down the esophagus, into the stomach, through the pylorus into the duodenum. The region can be directly visualized with the endoscopic camera while various procedures are performed. A plastic catheter is inserted and radiocontrast is injected into the bile ducts, and/or pancreatic duct. Fluoroscopy is used to look for blockages, or other lesions such as stones.

Overview of hospitals

The aim of the project is to perform measurements in 3 different hospitals per procedure. In every hospital minimum 10 patients are included per procedure. Following hospitals contributed to the measurement campaign:

- RF ablations
  - Hospital A
  - Hospital B
  - Hospital C
- TIPS
  - Hospital A
  - Hospital D
  - Hospital E
- Cerebral embolizations
  - Hospital A
  - Hospital D
  - Hospital F
- Embolizations of the vena spermatica
  - Hospital D
  - Hospital G
  - Hospital H
- Chemo embolization of the liver
  - Hospital E
  - Hospital L
- AV fistula for hemodialysis
  - Hospital A
  - Hospital F

  N.B. : 2 instead of 3 centres, because this procedure was canceled as the skin doses were low (cf page 12, sub **Number of Measurements**)
- Biliary drainages
  - Hospital B
  - Hospital D
  - Hospital K
- ERCP
  - Hospital G
  - Hospital I
  - Hospital J

The measurements for the chemo-embolizations of the liver were added during the measurement campaign and are performed in only 2 hospitals. The procedure was added as it is a very complex procedure and high doses can be expected. Moreover, the same region of the patient is irradiated as for the TIPS procedure, which makes it interesting to investigate if similar trigger levels can be found. In hospital E, the frequency was very low and only 2 patients were monitored during the measurement campaign.

Skin dose measurements

Thermoluminescent dosemeters

Skin dose measurements were performed using thermoluminescent dosemeters (TLDs). A TLD measures ionizing radiation exposure by measuring the amount of visible light emitted from a crystal in the detector when the crystal is heated. The amount of light emitted is dependent upon the radiation exposure. TLDs are tissue equivalent, which make them invisible on radiographic or fluoroscopic images. TLDs also measure the back scatter radiation from the patient.
The type of TLDs that are used for this project are LiF crystals, doped with magnesium and titanium (LiF:Mg,Ti). The energy dependence of this type of detectors is given in figure 2 (curve ■) [Olko *et al*, 2002].

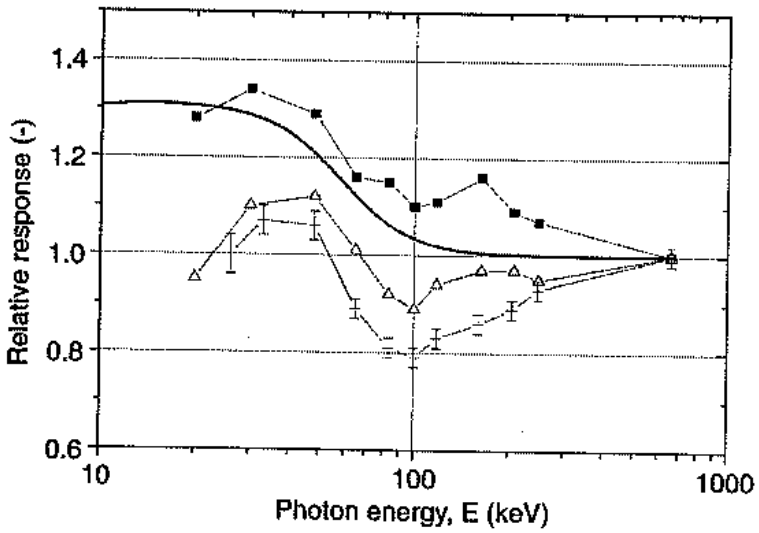


Figure 2: Energy dependence of LiF:Mg,Ti TLDs (curve ■)

During the measurement campaign, the TLDs were calibrated at the secondary calibration laboratory of SCK-CEN. The calibration was performed with the calibration detectors in a plexi holder and irradiated with a Cs-source (0,667 MeV). An energy correction factor of 1.20, relative to a reference X-ray beam of 65 keV, was applied. Background TLDs were kept for every measurement and the background signal was subtracted from the measured TL signals. Every TLD-reading was also corrected for the individual sensitivity of the respective TLD.
After each measurement, the TLDs were reset by annealing them at 400°C for 1 hour and at 100°C for 2 hours.

An uncertainty of 4% is assumed on the individual sensitivity factor and an uncertainty of 3% is determined for the calibration factor. From the data collected in the hospitals, an average beam energy of 50 keV (range:

43-55 keV) is found for the measurements. This implies an extra uncertainty related to the energy dependence response of the TLDs, relative to the energy used for the calibration (65 keV) of 10 %. A total uncertainty of 11% is determined for the TLD measurements.

Patient skin dose measurements

Interventional procedures can be very complex and not standardized in terms of X-ray projections and field sizes. This makes it difficult to predict before the procedure is started, where the maximum skin dose will be reached. Therefore, a grid of TLDs is used, in order to be sure that the maximum skin dose will be measured somewhere on the patient.
Different 'TLD sheets' were made for the different selected procedures, which could easily be wrapped around the irradiated part of the patient.

- ***RF ablations, TIPS procedure, Biliary drainages and chemo-embolizations of the liver***: For every single measurement 50 TLDs were used, placed in a grid of 10 by 5 TLDs (figure 3).

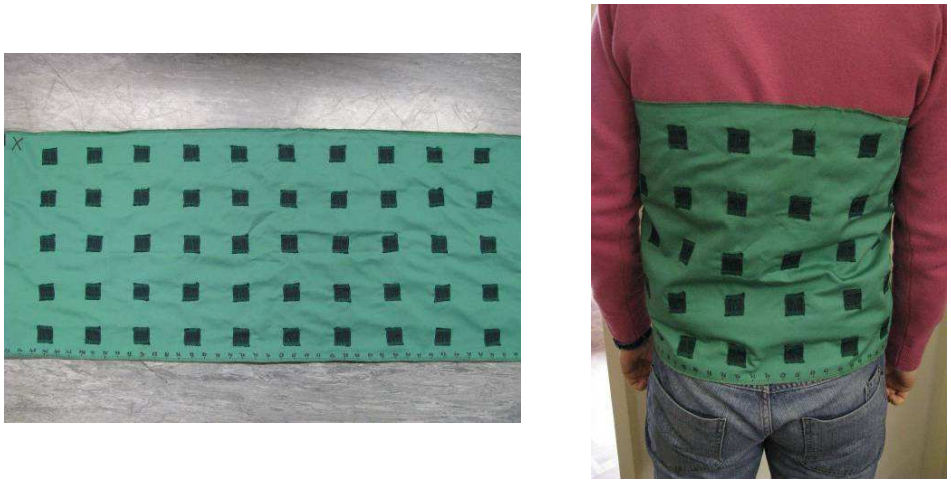


Figure 3: TLD sheets used for the RF ablations, TIPS, biliary drainages and chemo-embolizations of the liver

- **Embolizations of the vena spermatica and ERCP procedures**: For every single measurement 50 TLDs are used, placed in a grid of 10 by 5 TLDs (figure 4). Often these procedures are performed on X-ray equipment with a tube-above configuration. As the groin region needs to be accessible for the catheter insertion, the sheets are adjusted accordingly.
  This type of sheet is also used for biliary drainages with tube-under configuration and when frontal and lateral percutaneous access is required.

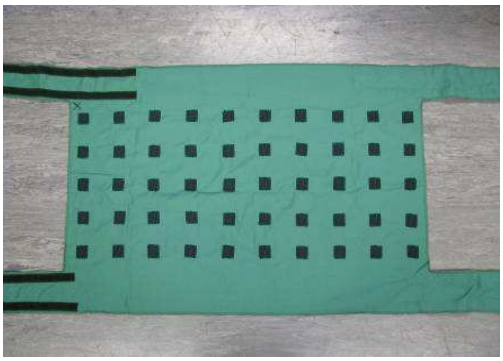


Figure 4: TLD sheets used for embolizations of the vena spermatica and biliary drainages where frontal and lateral access is required

- **Cerebral embolizations**: For every single measurement 38 TLDs are used and attached on a hospital hat (figure 5).

Figure 5: TLD hat used for cerebral embolizations

- **AV fistula for hemodialysis**: for every single measurement 12 TLDs are used, placed in a grid of 4 by 3 TLDs (figure 6).

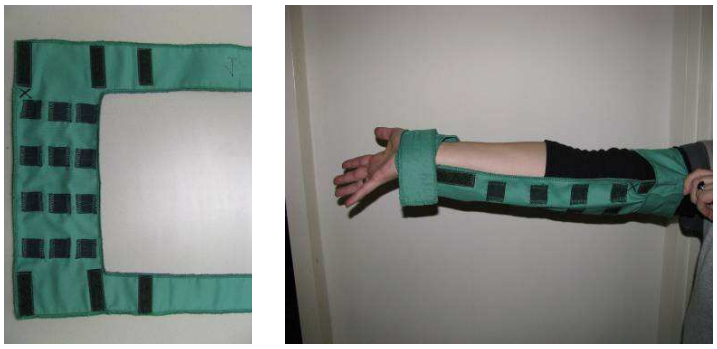


Figure 6: TLD sheet used for AF fistula for hemodialysis

Data collection

Next to skin dose measurements, we collected some data during the procedure for further analysis.
First of all, we registered the total DAP-value and Cumulative Dose Index (CDI), if available.
The Cumulative dose index is defined by the International Electrotechnical Commission [IEC] standard 60601-2-43 to be the free-in-air kerma at the reference point 15 cm towards the x-ray tube from the isocenter for a C-arm fluoroscopy system.

For the RF ablations, TIPS procedures, chemo-embolizations of the liver, embolizations of the vena spermatica and biliary drainages we collected patient data, such as contour of the chest or abdomen, weight and length. For these procedures a length scale is drawn on the TLD sheet to be able to register the contour of the patient easily.

If possible also some procedure related data were collected:

- range of tube voltage
- range of tube current (mA) or tube load (mAs)
- copper filtration
- fluoroscopy time
- number of images

DAP meter calibrations

The DAP-meters in the hospitals were calibrated with the Radcal Patient Dose Calibrator (PDC). This chamber is calibrated and validated at the standard laboratory of Ghent.

The following protocol was determined:

- A DAP calibration was done without the table present. When more time was available, a calibration was also performed with the table present.
- The clinical program that is used for the TRIR project was selected for the DAP calibration
- A PMMA phantom or lead was used, such that clinically relevant parameters were reached.

All DAP values determined during the measurement campaign were corrected according the obtained calibration factor.

Therefore, the project partners clearly emphasizes that all trigger levels can only be applied for DAP meters with calibration factors between [0,80 – 1,20].

Results

Number of measurements

In total, measurements are performed on 179 patients, from which
- 35 patients for the ERCP procedures,
- 30 patients for RF ablations,
- 30 patients for cerebral embolizations,
- 26 for biliary drainages,
- 20 patients for embolizations of the vena spermatica,
- 18 patients for the TIPS procedures,
- 12 patients for the chemo-embolizations of the liver,
- 8 patients for the AV fistula for hemodialysis.

All data were collected over a period of 20 months (from November 2008 until June 2010).
For the embolizations of the vena spermatica, data from 20 more procedures were received from another project, conducted at hospital D. This means that an analysis was performed on a total of 199 patient skin dose data.
TIPS procedures are very complex but are not performed in many hospitals and in some hospitals only around 10 cases per year are performed. In one of the hospitals (Hosp E) it was not possible to perform more than 2 measurements for this procedure.
The AV fistula for hemodialysis are also non-frequently performed procedures. This procedure was included after special request from some interventional radiologists, but it was soon noticed that these procedures do not introduce any skin damage concerns for the patient. Therefore and because of the lack of available procedures, minimal focus was given to these procedures and only few measurements were performed.

Overview of collected data

Equipment, patient and procedure data

In tables 1 (a to h), an overview is given of all collected data on the equipment, patients and procedure parameters.

RF ablations										
Hospital	Date	Patient data				Procedure parameters				
		contour [cm]	length [m]	weight [kg]	BMI	Tube voltage [kVp]	Tube current [mA]	Cu filtration [mm]	Scopy time [min]	# frames
Hospital A Siemens Axiom Artis Flat panel Bi-plane configuration	30/04/2009	140	1.57	52	21	81	310	0	61	344
	27/05/2009	160	1.78	97	31	100	525	0	81.6	968
	29/06/2009	142	1.81	90	27	87	675	0	47	318
	20/08/2009	128	1.92	72	20	81	458	0	15	16
	20/08/2009	120	1.72	70	24	85	558	0	38	274
	14/09/2009	130	1,65	58	21	86	560	0	22,12	214
	15/09/2009	150	1,97	120	31	100	525	0	113	634
	23/09/2009	132	1,7	67	23	79	571	0.2 - 0.9	136	1118
	29/09/2009	155	1,74	75	25	81	372	0	30,8	12
	13/10/2009	160	1,78	104	33	100	657	0,1	15,2	18
	Mean	**142**	**1,76**	**81**	**26**	**88**	**521**		**56**	**392**
Hospital B Siemens Coroscop C Image intensifier Under-table configuration	3/06/2009	110	1,7	96	33	82	5,9	/	12,4	/
	10/06/2009	102	1,69	85	30	88	6,8	/	19,3	/
	29/07/2009	108	1,71	85	29	87	5,2	/	7,7	/
	29/07/2009	108	1,7	80	28	74	5,1	/	29,5	/
	30/09/2009	110	1,75	90	29	90	10	/	27,7	/
	25/11/2009	135	1,72	139	47	96	10	/	44,5	/
	26/11/2009	122	1,8	120	37	98	10	/	6,2	/
	2/12/2009	114	1,84	110	32	85	8,0	/	7,4	/
	1/3/2010	102	1.75	80	26	95	10	/	10.8	/
	3/3/2010	98	1.8	80	25	92	10	/	14.3	/
	Mean	**111**	**1.75**	**97**	**32**	**89**	**8.1**		**18**	
Hospital C Toshiba Image intensifier Under-table configuration	9/11/2009	114	1,75	84	27	80	120	/	31,8	44
	18/11/2009			54		80	/	/	16,9	6
	22/01/2010	98	1,8	92	28	75	130	/	13,2	
	22/01/2010	96	1,77	65	21	73	/	/	4,2	0
	09/04/2010	77	1.53	45	19	75	320	/	1.5	
	09/04/2010	116	1.79	80	25	77	450	/	25.3	224
	14/04/2010	106	1.64	93	35	75	137	/	28.1	
	14/04/2010		1.87	83	24	75	340	/	30.7	111
	18/04/2010		1.62	58	22	80	137	/	24.4	
	28/04/2010	116	1.58	69	28	73	530	/	25.5	
	Mean	**103**	**1.71**	**72**	**25**	**76**	**330**		**20**	**77**

(a)

TIPS										
hospital	date	patient data				Procedure parameters				
		contour [cm]	length [m]	weight [kg]	BMI	Tube voltage [kVp]	Tube load [mA]	Cu filtration [mm]	Scopy time [min]	# frames
Hospital A	29/09/2009	107	1,58	58	23	80	207	0	58	195
	23/09/2009	110	1,66	75	27	80	357	0	13	288
	15/09/2009	114	1,8	90	28	81	493	0	10,17	271
Philips Allura FD20	2/09/2009	108	1,88	84	24	81	414	0	16	588
	13/08/2009*	124	1,7	80	28	77	327	0,1	16,42	161
Flat panel	6/08/2009	106	1,86	74	21	80	479	0	18,24	703
	17/07/2009	95	1,56	50	21	81	264	0	13,52	342
Under-table configuration	1/07/2009	96	1,69	63	22	90	250	0	17	1013
	16/06/2009	110	1,83	87	26	87	571	0	17	635
	22/04/2009	111	1,85	80	23	82	425	0	13,43	329
	Mean	**108**	**1,74**	**74**	**24**	**82**	**379**		**19**	**453**
Hospital D	20/01/2010	108	1,65	73	27	81	334	0	164	285
	22/01/2010	92	1,7	50	17	75	326	0.1	47	388
Siemens	02/04/2010	92	1.58	58	23	79	396	0-0.1	59.2	664
Flat panel	14/04/2010	122	1.6	60	23	79	799	0-0.3	29.1	206
	26/05/2010		1.6	62	24	77	538	0.1	115.8	202
Under-table configuration	16/06/2010		1.72	65	22	78	579	0.1	49	260
	Mean	**104**	**1.64**	**61**	**23**	**78**	**495**		**77**	**334**
Hospital E	3/06/2009		1,66	59	21	90		0,2	15,4	114
Siemens Axiom	25/05/2010	86	1.65	54	20	91	458	0-01	25	98
Under-table configuration										
	Mean	**86**	**1.66**	**56**	**21**	**91**	**458**		**20**	**106**

* This procedure is performed on another X-ray machine: Siemens Artis Zee – bi-plane with flat panel detectors

(b)

Cerebral embolizations											
hospital	Date	patient data				Procedure parameters					
		contour [cm]	length [m]	weight [kg]	BMI	Tube voltage [kVp]	Tube current [mA]	Cu filtration [mm]	Scopy time [min]	# frames
Hospital A Siemens Artis Zee Flat panel Bi-plane	13/10/2009	/	/	/	/	78	156,0	0 - 0.1	25,1	658
	29/09/2009	/	/	/	/	75	222	0 - 0.1	15,2	582
	9/09/2009	/	/	/	/	76	208	0 - 0.1	14,5	486
	8/09/2009	/	/	/	/	86	181	0	13,4	937
	14/08/2009	/	/	/	/	73	181	0 - 0.1	1,28	355
	14/07/2009	/	/	/	/	77	182	0,1	10,5	735
	12/05/2009	/	/	/	/	80	219	0 - 0.1	21,1	738
	29/06/2009	/	/	/	/	75	201	0 - 0.1	15,2	830
	23/06/2009	/	/	/	/	80	134	0 - 0.1	21,1	578
	5/05/2009	/	/	/	/	78	190	0 - 0.1	52,4	508
	Mean					**78**	**187**		**19**	**641**
Hospital D Siemens Flat panel Bi-plane	21/12/2009	/	/	/	/	77	330	0 - 0.1	57,6	978
	14/12/2009	/	/	/	/	78	279	0	62,8	960
	7/12/2009	/	/	/	/	74	282	0 - 0.1	21,6	776
	6/01/2010	/	/	/	/	73	338	0,1	25,6	1148
	18/01/2010	/	/	/	/	72	310	0 - 0.2	21	1777
	25/01/2010	/	/	/	/	77	273	0	55,8	744
	3/02/2010	/	/	/	/	79	286	0 - 0.1	72	1045
	10/02/2010	/	/	/	/	73	315	0 - 0.2	66.9	1188
	24/02/2010	/	/	/	/	73	322	0 - 0.1	28.7	1118
	01/03/2010	/	/	/	/	80	297	0 - 0.1	119.1	864
	Mean					**76**	**303**		**53**	**1060**
Hospital F Toshiba Infinitix Image intensifier Under-table configuration	19/10/2009	/	/	/	/	/	/	/	/	/
	13/10/2009	/	/	/	/	/	/	/	21	/
	20/08/2009	/	/	/	/	/	/	/	/	/
	20/08/2009	/	/	/	/	/	/	/	/	/
	13/08/2009	/	/	/	/	/	/	/	/	/
	13/08/2009	/	/	/	/	78	400	/	31,2	/
	10/07/2009	/	/	/	/	80	400	/	28,6	/
	10/07/2009	/	/	/	/	80	450	/	21,3	/
	16/07/2009	/	/	/	/	/	/	/	/	/
	16/07/2009	/	/	/	/	/	/	/	/	/
	Mean					**79**	**417**	/	**26**	/

(c)

Embolizations of the vena spermatica										
hospital	date	patient data				Procedure parameters				
		contour [cm]	length [m]	weight [kg]	BMI	Tube voltage [kVp]	Tube current [mA]	Cu filtration [mm]	Scopy time [min]	# frames
Hospital D Siemens Iconos R300 Image intensifier Above-table configuration			2	84	21	85	/	0	14,1	13
			1,72	72	24	85	/	0	13,5	9
			2	57	14	85	/	0	21,3	16
			1,76	84	27	85	/	0	15,7	14
			1,69	61	21	85	/	0	37,1	12
			1,79	64	20	70	/	0,1	11,2	13
			1,94	80	21	85	/	0	36	21
			1,75	87	28	85	/	0	43,7	32
			1,78	59	19	75	/	0,2	15,2	11
			1,67	57	20	70	/	0,1	10,6	11
			1,61	45	17	70	/	0,1	12	11
			1,82	88	27	85	/	0	52,7	13
			1,58	40	16	70	/	0,1	10,6	11
			1,72	52	18	75	/	0,2	17,7	10
			1,82	88	27	85	/	0	52,7	14
			1,67	50	18	70	/	0,1	29,5	16
			1,87	74	21	85	/	0	15,1	12
			1,98	87	22	85	/	0	26,2	17
			1,61	44	17	70	/	0,1	27,2	15
			1,79	74	23	85	/	0	22,8	14
	Mean		**1,8**	**67**	**21**	**80**		**0,1**	**24,3**	**14**
Hospital G Siemens CGR Prestlix Image intensifier Above-table configuration	19/06/2009		1,86	78	23	77	100	0	26	12
	2/04/2009		1,75	54	18	77	100	0	11	12
	3/04/2009		1,69	60	21	77	100	0	11	12
	5/03/2009		1,77	70	22	77	100	0	10	12
	12/03/2009		1,58	41	16	70	100	0	20	15
	29/01/2009		1,8	37	11	77	100	0	18	15
	27/01/2009		1,44	37	18	73	100	0	12	12
	13/01/2009	child		42		73	100	0	57	12
	23/12/2008		1,65	50	18	73	100	0	11	9
	9/12/2008					73	100	0	12	9
	Mean		**1,69**	**52**	**18**	**75**	**100**	**0**	**19**	**12**
Hospital H Siemens Iconos R200 Image intensifier Above-table configuration	14/04/2009	child				73	802	0	16	4
	26/05/2009	medium	1,93	90	24	73	797	0	3,13	2
	14/09/2009	small				73	815	0	5,37	4
	28/09/2009	small				73	806	0	3,55	3
	19/10/2009	medium				73	817	0	5,23	4
	26/10/2009	small				73	824	0	8,46	4
	2/11/2009	medium				73	826	0	3,58	2
	30/11/2009	small				73	829	0		4
	4/12/2009	medium				73	700	0	9	5
	26/02/2010	small				73			6,39	4
	Mean					**73**	**802**	**0**	**6,7**	**4**

(d)

Chemo-embolizations of the liver										
hospital	Date	patient data				Procedure parameters				
		contour [cm]	length [m]	weight [kg]	BMI	Tube voltage [kVp]	Tube load [mA]	Cu filtration [mm]	Scopy time [min]	# frames
Hospital E	12/09/2009	/	/	/	/	/	/	/	/	/
	12/01/2010	100	1,55	78	32	80	795	0	5	66
Hospital K	23/02/2010		1.75	65	21	73	/	/	13	145
Hospital L Siemens Image intensifier Under-table configuration	16/11/2009	97				/	/	/	/	/
	16/11/2009					/	/	/	/	/
	16/11/2009	108				/	/	/	/	/
	14/12/2009	126	1,69	106	37	/	/	/	/	/
	29/01/2010					/	/	/	/	/
	08/02/2010		1.78	68	21	/	/	/	/	/
	10/02/2010		1.59	60	24	/	/	/	/	/
	10/03/2010	88	1.63	60	23	/	/	/	/	/
	20/04/2010	89	1.68	63	22	/	/	/	/	/
	20/04/2010					/	/	/	/	/
	Mean	**102**	**1.67**	**71**	**25**					

(e)

AV fistula for hemodialysis										
hospital	date	patient data				Procedure parameters				
		contour [cm]	length [m]	weight [kg]	BMI	Tube voltage [kVp]	Tube load [mAS]	Cu filtration [mm]	Scopy time [min]	# frames
Hospital A Philips Allura FD20 Image intensifier Under-table configuration	23/09/2009*	/	/	/	/	64		0,3	14,2	116
	14/09/2009	/	/	/	/	65	7,5	0	2,2	75
	20/08/2009*	/	/	/	/	65		0,3	3,39	31
	22/07/2009	/	/	/	/	65	33	0	5,36	80
	30/06/2009	/	/	/	/	65	23	0	18,24	77
	26/05/2009	/	/	/	/	60	8	0	25	78
	19/05/2009	/	/	/	/	65	13	0	2,41	19
	Mean					**64**	**17**		**10**	**68**
Hospital F	29/07/2009	/	/	/	/	76	200 mA	/	11,4	/

* This procedure is performed on another X-ray machine: Siemens Artis Zee – under-table configuration with flat panel detector

(f)

Biliary drainages										
hospital	date	patient data				Procedure parameters				
		contour [cm]	length [m]	weight [kg]	BMI	Tube voltage [kVp]	Tube current [mA]	Cu filtration [mm]	Scopy time [min]	# frames
Hospital B Siemens Siregraph D Image intensifier Above-table configuration	17/09/2009	82	1,55	45	19	68	2,6	/	12,4	5
	10/09/2009	102	1,58	60	24	93	2,6	/	6,3	2
	10/09/2009	112	1,6	55	21	90	2,4	/	8,2	4
	3/09/2009	107	1,69	86	30	95	2,8	/	3	2
	30/07/2009	98	1,56	55	23	93	2,5	/	4,8	4
	25/06/2009	105	1,71	65	22	99	3	/	4,2	5
	25/06/2009	120	1,6	71	28	109	4	/	6,9	2
	25/06/2009	123	1,6	90	35	103	3,3	/	21,2	5
	28/05/2009	105	1,66	63	23	96	2,8	/	5	0
	18/02/2010*	106	1.5	66	29	77	440	0-0.1	4	6
	18/02/2010*	90	1.62	62	24	77	440	0	2.2	6
	Mean	**105**	**1.61**	**65**	**25**	**91**			**7**	**4**
Hospital D Image intensifier Flat panel Under-table configuration	4/01/2010	87	1,62	58,8	22	77	375	/	34,2	120
	8/01/2010	89	1,68	60	21	73	404	0.1 - 0.2	11,4	42
	27/01/2010	84	1,65	59	22	70	431	0.1 - 0.3	15,7	17
	28/01/2010	98	1,78	77	24	80	419	0 - 0.1	49.4	227
	24/02/2010	104	1.82	90	27	82	614		122.6	356
	31/03/2010	76	1.74	76	25	78	700		47.25	129
	10/05/2010	114	1.57	68	28	76	388	0.1 - 0.3	47	130
	20/05/2010	106	1.79	72	22	79	408		42.9	153
	02/06/2010		1.78	127	40	91	512	0 - 0.1	105.4	43
	09/06/2010		1.62	63	24	74	389	0.1 - 0.2	33	37
	09/06/2010		1.89	92	26	77	490	0 - 0.3	69.1	170
	Mean	**95**	**1.72**	**77**	**26**	**78**	**466**		**53**	**129**
Hospital E Siemens Axiom Artis	10/08/2009		1,8	69	21	80	110	0,2	40	28
	13/05/2009		1,7	50	17	80	50-100	0,2	39,37	92
	08/04/2010	75	1.56	52	21	72	400	0.2	47.2	9
	Mean		**1.69**	**57**	**20**	**77**		**0.2**	**42.2**	**43**
Hospital K	5/11/2009	109	1,68	61	22	80	/	/	10,6	0

* This procedure is performed on another X-ray machine: Siemens Artis Zee - above-table configuration with image intensifier

(g)

ERCP										
hospital	Date	patient data				Procedure parameters				
		contour [cm]	length [m]	weight [kg]	BMI	Tube voltage [kVp]	Tube load [mAs]	Cu filtration [mm]	Scopy time [min]	# frames
Hospital G Siemens CGR Prestilix 1600 Image intensifier Above-table configuration	19/11/2007	/	/	/	/	/	/	/	/	/
	19/11/2007	/	/	/	/	/	/	/	/	/
	19/11/2007	/	/	/	/	/	/	/	/	/
	3/12/2007	/	/	/	/	/	/	/	/	/
	3/12/2007	/	/	/	/	/	/	/	/	/
	17/12/2007	/	/	/	/	/	/	/	/	/
	21/02/2008	/	/	/	/	/	/	/	/	/
	29/02/2008	/	/	/	/	/	/	/	/	/
	29/02/2008	/	/	/	/	/	/	/	/	/
	29/02/2008	/	/	/	/	/	/	/	/	/
	17/03/2008	/	/	/	/	/	/	/	/	/
	Mean									
Hospital I Siemens Polystar Image intensifier Under-table configuration	16/11/2007	/	1,73	73,5	25	85	2,4	0,1	3,2	/
	23/11/2007	/	1,55	68	28	94	2,6	0,1	1	/
	23/11/2007	/	1,64	63	23	86	2	0,1	13,4	/
	23/11/2007	/	1,72	64	22	84	1,8	0,1	10,8	/
	28/11/2007	/	1,57	57	23	83	2,5	0,1	4,1	/
	29/11/2007	/	1,71	65	22	91	2,9	0,1	1,9	/
	29/11/2007	/	1,59	81	32	96	2,7	0,1	3,3	/
	6/12/2007	/	1,78	95	30	94	2,8	0,1	1,7	/
	6/12/2007	/	1,6	58	23	89	2,3	0,1	9,3	/
	28/12/2007	/	1,69	90	32	80	2,8	0,1	1,7	/
	15/01/2008	/	1,65	65	24	91	2,6	0,1	5,2	/
	15/01/2008	/	1,82	79	24	101	3,3	0,1	14,3	/
	17/01/2008	/	1,69	100	35	97	2,9	0,1	2,4	/
	22/01/2008	/	1,48	44	20	67	2,1	0,1	1,6	/
	Mean		**1,66**	**73**	**26**	**89**	**2,7**	**0,1**	**4,55**	/
Hospital J Siemens CGR Prestilix 1600 Image intensifier Above-table configuration	23/11/2007	/		100		81	100	0,5	1	/
	27/11/2007	/	1,82	95	29	85	80	0,5	1,6	/
	10/12/2007	/	1,55	56	23	81	100	0,5	0.08	/
	11/12/2007	/	1,71	76	26	81	100	0,5	8,42	/
	17/12/2007	/	1,53	55	23	77	100	0,5	1,2	/
	24/12/2007	/	1,86	90	26	85	100	0,5	1,03	/
	28/01/2008	/	1,60	65	25	73	100	0,5	1,14	/
	4/02/2008	/		70		81	100	0,5	2,9	/
	21/03/2008	/	1,80	85	26	90	100	0,5	1,06	/
	21/03/2008	/	1,70	85	29	90	100	0,5	0,45	/
	Mean		**1,70**	**75**	**26**	**83**	**98**	**0,5**	**2,2**	

(h)

Table 1: overview of collected data on equipment, patient and procedure data

Dose data

In tables 2 (a to h), an overview is given of the dose data displayed on the equipment and the maximum skin doses measured with the TLDs.

RF ablations				
hospital	**Date**	**DAP [µGy.m²]**	**CDI [mGy]**	**Max. skin dose [mGy]**
Hospital A Siemens Axiom Artis Flat panel Bi-plane configuration	13/10/2009	7687	977	977
	29/09/2009	2811	462	602
	23/09/2009	8606	1554	1167
	15/09/2009	11033	1691	2303
	14/09/2009	1429	249	232
	20/08/2009	6170	910	1325
	20/08/2009	913	165	118
	29/06/2009	9552	1355	766
	27/05/2009	21506	3067	2638
	30/04/2009	2630	406	391
	Mean	**7234**	**1084**	**1052**
Hospital B Siemens Coroscop C Image intensifier Under-table configuration	3/06/2009	3932	/	562
	10/06/2009	20659	/	2374
	29/07/2009	4412	/	630
	29/07/2009	13774	/	2530
	30/09/2009	35532	/	4060
	25/11/2009	79292	/	11821
	26/11/2009	9759	/	944
	2/12/2009	8034	/	795
	1/3/2010	12433	/	1701
	3/3/2010	20921	/	1216
	Mean	**20875**		**2663**
Hospital C Toshiba Image intensifier Under-table configuration	9/11/2009	16373	/	1335
	18/11/2009	1342	/	264
	22/01/2010	6841	/	351
	22/01/2010	639	/	65
	09/04/2010	11522	/	1289
	09/04/2010	77	/	8
	14/04/2010	5638	/	681
	14/04/2010	4899	/	1157
	18/04/2010	2922	/	617
	28/04/2010	4644	/	568
	Mean	**5490**		**633**

(a)

TIPS				
hospital	**Date**	**DAP [µGy.m²]**	**CDI [mGy]**	**Max. skin dose [mGy]**
	29/09/2009	74684	1890	5088
	23/09/2009	84338	2015	4247
	15/09/2009	67908	1891	4494
Hospital A	2/09/2009	96884	2628	4396
Philips Allura FD20	13/08/2009	35651	1158	1682
Flat panel	6/08/2009	114978	3547	7195
	17/07/2009	43698	1431	2685
Under-table configuration	1/07/2009	57056	1728	2894
	16/06/2009	142423	4096	7516
	22/04/2009	88368	2526	5112
	Mean	**80599**	**2291**	**4531**
	20/01/2010	70098	5872	6810
Hospital D	22/01/2010	39407	2368	2887
Siemens	02/04/2010	57507	4052	4294
Flat panel	14/04/2010	28305	1333	673
	26/05/2010	32828	2309	2008
Under-table configuration	16/06/2010	34661	2119	2393
	Mean	**43801**	**3009**	**3177**
	3/06/2009	16894	1361	1793
Hospital E	25/05/2010	16213	1797	1700
Siemens Axiom				
Under-table configuration				
	Mean	**16554**	**1579**	**1746**

* This procedure is performed on another X-ray machine: Siemens Artis Zee – bi-plane with flat panel detectors

(b)

Cerebral embolizations				
hospital	**Date**	**DAP [µGy.m²]**	**CDI [mGy]**	**Max. skin dose [mGy]**
	13/10/2009	18005	1878	1572
	29/09/2009	11740	1037	1084
	9/09/2009	11383	1231	1017
Hospital A	8/09/2009	25864	2264	1883
Siemens Artis Zee	14/08/2009	3732	206	180
Flat panel	14/07/2009	13331	1313	1658
Bi-plane	12/05/2009	19136	2426	1203
	29/06/2009	11718	990	1041
	23/06/2009	11982	1505	1451
	5/05/2009	34346	3710	2252
	Mean	**16124**	**1656**	**1334**
	21/12/2009	19665	2873	1219
	14/12/2009	19763	3745	2511
	7/12/2009	10308	1472	803
Hospital D	6/01/2010	19222	3079	2003
Siemens	18/01/2010	18736	2064	1335
Flat panel	25/01/2010	15114	2433	1606
Bi-plane	3/02/2010	21792	3362	1976
	10/02/2010	23708	2730	1634
	17/02/2010	17136	2570	816
	17/02/2010	42147	6347	4106
	Mean	**20759**	**3068**	**1801**
	19/10/2009	17990	/	2301
	13/10/2009	18903	1082	1911
	20/08/2009	38836	2139	5033
Hospital F	20/08/2009	27209	1669	4367
Toshiba Infinitix	13/08/2009	22868	1647	2411
Image intensifier	13/08/2009	33944	2717	5003
Under-table configuration	10/07/2009	22360	1849	2833
	10/07/2009	16017	1113	1607
	16/07/2009	41143	3176	3675
	16/07/2009	38113	3364	3363
	Mean	**27738**	**2084**	**2801**

(c)

Embolizations of the vena spermatica				
hospital	**Date**	**DAP [µGy.m²]**	**CDI [mGy]**	**Max. skin dose [mGy]**
Hospital D Siemens Iconos R300 Image intensifier Above-table configuration		301	/	96
		365	/	114
		350	/	152
		1815	/	674
		640	/	504
		224	/	81
		937	/	293
		2597	/	1823
		153	/	82
		208	/	85
		107	/	44
		1100	/	464
		146	/	61
		158	/	48
		1032	/	549
		872	/	646
		358	/	77
		698	/	287
		896	/	282
		489	/	238
	Mean	**672**		**330**
Hospital G GE Prestilix 1600 Image intensifier Above-table configuration	19/06/2009	14386	/	765
	2/04/2009	4137	/	112
	3/04/2009	2035	/	161
	5/03/2009	2851	/	196
	12/03/2009	2885	/	173
	29/01/2009	4137	/	482
	27/01/2009	1700	/	159
	13/01/2009	8958	/	1231
	23/12/2008	1888	/	136
	9/12/2008	2675	/	142
	Mean	**4575**		**359**
Hospital H Siemens Iconos R200 Image intensifier Above-table configuration	14/04/2009	816	69	74
	26/05/2009	411	/	32
	14/09/2009	1165	/	73
	28/09/2009	403	/	30
	19/10/2009	1079	59	64
	26/10/2009	1715	122	156
	2/11/2009	349	28	22
	30/11/2009	930	36	44
	4/12/2009	4083	194	259
	26/02/2010	924	44	94
	Mean	**1187**	**79**	**86**

(d)

Chemo-embolizations of the liver				
hospital	**Date**	**DAP [µGy.m²]**	**CDI [mGy]**	**Max. skin dose [mGy]**
Hospital E	12/09/2009	8511	339	441
	12/01/2010	9899	429	141
Hospital K	23/02/2010	27600	/	1791
Hospital L Siemens Image intensifier Under-table configuration	16/11/2009	32732	/	2432
	16/11/2009	38400	/	2591
	16/11/2009	44431	/	2681
	14/12/2009	43581	/	3776
	29/01/2010	42785	/	3598
	08/02/2010	22543	/	1181
	10/02/2010	39801	/	2506
	10/03/2010	14560	/	1611
	20/04/2010	8498	/	395
	20/04/2010	-	/	4676
	Mean	**31926**		**2558**

(e)

AV fistula for hemodialysis				
hospital	**Date**	**DAP [µGy.m²]**	**CDI [mGy]**	**Max. skin dose [mGy]**
Hospital A Philips Allura FD20 Image intensifier Under-table configuration	23/09/2009	789	39	36
	14/09/2009	990	28	16
	20/08/2009	535	23	19
	22/07/2009	1059	113	97
	30/06/2009	1787	105	119
	26/05/2009	2382	113	114
	19/05/2009	93	16	17
	Mean	**1091**	**62**	**60**
Hospital F	29/07/2009	234	16	36

* This procedure is performed on another X-ray machine: Siemens Artis Zee – under-table configuration with flat panel detector

(f)

Biliary drainages				
hospital	**Date**	**DAP [µGy.m²]**	**CDI [mGy]**	**Max. skin dose [mGy]**
Hospital B Siemens Siregraph D Image intensifier Above-table configuration	17/09/2009	2565	/	492
	10/09/2009	1803	/	333
	10/09/2009	2111	/	264
	3/09/2009	1877	/	216
	30/07/2009	2045	/	247
	25/06/2009	2270	/	280
	25/06/2009	4121	/	509
	25/06/2009	12629	/	1673
	28/05/2009	2105	/	174
	18/02/2010*	3298	124	242
	18/02/2010*	873	56	94
	Mean	**3245**	**/**	**411**
Hospital D Image intensifier Flat panel Under-table configuration	4/01/2010	6063	492	409
	8/01/2010	5050	443	334
	27/01/2010	2469	343	330
	28/01/2010	38432	3876	3229
	24/02/2010	10460	819	1159
	31/03/2010	52390	5855	5633
	10/05/2010	7690	988	577
	20/05/2010	12497	1427	1413
	02/06/2010	43134	10501	6424
	09/06/2010	14983	2074	1656
	09/06/2010	3495	381	285
	Mean	**17879**	**2473**	**1957**
Hospital E Siemens Axiom Artis	10/08/2009	13026	1657	1296
	13/05/2009	14501	1404	919
	08/04/2010	3981	580	560
	Mean	**10503**	**1214**	**925**
Hospital K	5/11/2009	11420	/	1279

* This procedure is performed on another X-ray machine: Siemens Artis Zee - above-table configuration with image intensifier

(g)

ERCP				
hospital	**Date**	**DAP [µGy.m²]**	**CDI [mGy]**	**Max. skin dose [mGy]**
Hospital G Siemens CGR Prestilix 1600 Image intensifier Above-table configuration	19/11/2007	286	/	12
	19/11/2007	6087	/	347
	19/11/2007	3177	/	151
	3/12/2007	7107	/	405
	3/12/2007	7441	/	327
	17/12/2007	44	/	2
	21/02/2008	6632	/	527
	29/02/2008	2806	/	157
	29/02/2008	2445	/	157
	29/02/2008	2383	/	149
	17/03/2008	1586	/	175
	Mean	**3468**		**219**
Hospital I Siemens Polystar Image intensifier Under-table configuration	16/11/2007	1148	/	72
	23/11/2007	2063	/	106
	23/11/2007	5341	/	335
	23/11/2007	2588	/	158
	28/11/2007	1922	/	109
	29/11/2007	1268	/	65
	29/11/2007	2350	/	111
	6/12/2007	1115	/	78
	6/12/2007	1915	/	224
	28/12/2007	1201	/	79
	15/01/2008	4382	/	302
	15/01/2008	6490	/	664
	17/01/2008	2497	/	173
	22/01/2008	1788	/	224
	Mean	**2493**		**203**
Hospital J Siemens CGR Prestilix 1600 Image intensifier Above-table configuration	23/11/2007	771	/	66
	27/11/2007	1064	/	76
	10/12/2007	52	/	4
	11/12/2007	4842	/	280
	17/12/2007	539	/	43
	24/12/2007	648	/	60
	28/01/2008	659	/	43
	4/02/2008	1676	/	267
	21/03/2008	607	/	43
	21/03/2008	555	/	33
	Mean	**1141**		**92**

(h)

Table 2: Overview of dose data displayed on equipment and maximum skin dose measured with TLDs

DAP calibrations

An overview is given in tables 3 to 10 of the attained DAP calibration factors for the DAP-meters used in the project.
In most cases, the DAP calibration factors deviate a lot when the table is present in the X-beam. However, in this study the calibration factors without the table should be used.

The Siemens Coroscop and the Siemens Siregraph X-ray systems used in hospital B, were replaced by the end of the project, before a DAP-calibration could be performed. The calibration factors given in the table were determined by the medical physicist in the hospital before the TRIR project. Both calibration factors, however, are determined with the table in the X-ray beam.
Most calibration factors without table present are within the range of [0.80 – 1.20]. Larger deviations are observed for the Toshiba system in hospital F and for the frontal tube of the Siemens Axiom Artis bi-plane system in hospital D. All DAP measurements performed in the hospitals (table 2) are corrected according to the corresponding calibration factor.

Hospital A

X-ray system	**Siemens Artis Zee bi-plane**		
		kVp	**CF = DAP_{ref}/DAP_{hosp}**
Without table	Frontal tube	70	0.85
		90	0.86
		125	0.87
	Lateral tube	70	0.89
		90	0.92
		125	0.93
With table		70	0.58

X-ray system	**Siemens Axiom Artis monoplane**	
	kVp	**CF = DAP_{ref}/DAP_{hosp}**
Without table	70	0.89
	90	0.89
	108	0.89
With table	70	0.63
X-ray system	**Philips Allura FD20 bi-plane**	
	kVp	**CF = DAP_{ref}/DAP_{hosp}**
Without table	66	0.94
	80	0.96
With table	70	0.60

Table 3: DAP calibration factors for the three systems used in hospital A

Hospital B

X-ray system	Siemens Siregraph D monoplane	
	kVp	**CF = DAP_{ref}/DAP_{hosp}**
Without table	50	0.95
	60	0.94
	70	0.94
	81	0.95
	90	0.97
	100	0.99
	109	1.00

X-ray system	Siemens Coroscop C monoplane	
	kVp	**CF = DAP_{ref}/DAP_{hosp}**
With table		0.90

X-ray system	Siemens Artis monoplane	
	kVp	**CF = DAP_{ref}/DAP_{hosp}**
Without table	70	0.86
	81	0.87

Table 4: DAP calibration factors for the three systems used in hospital B

Hospital C

X-ray system	Toshiba monoplane	
	kVp	**CF = DAP_{ref}/DAP_{hosp}**
Without table	54	1,02
	89	0,99

Table 5: DAP calibration factor for the system used in hospital C

Hospital D

X-ray system	Siemens Iconos R200	
	kVp	**CF = DAP_{ref}/DAP_{hosp}**
Without table	70	0.85
	81	0.87
	90	0.89

X-ray system	Siemens monoplane	
	kVp	CF = DAP_{ref}/DAP_{hosp}
Without table	70	0.94
	90	0.97
	117	0.98
With table	70	0.60

X-ray system	Siemens Axiom Artis bi-plane		
		kVp	CF = DAP_{ref}/DAP_{hosp}
Without table	Frontal tube	70	0.76
		90	0.77
		117	0.79
	Lateral tube	70	0.84
		90	0.85
		117	0.87
With table		70	0.58

Table 6: DAP calibration factors for the three systems used in hospital D

Hospital F

X-ray system	Toshiba monoplane	
	kVp	CF = DAP_{ref}/DAP_{hosp}
	78	1.28

Table 7: DAP calibration factor for the system used in hospital F

Hospital G

X-ray system	GE Prestilix 1600	
Without table	kVp	CF = DAP_{ref}/DAP_{hosp}
	65	1.04
	75	1.05
	85	1.06

Table 8: DAP calibration factor for the system used in hospital G

Hospital H

X-ray system	Siemens Iconos R200	
	kVp	CF = DAP_{ref}/DAP_{hosp}
Without table	70	0.93
	81	0.93
	102	0.96

Table 9: DAP calibration factor for the system used in hospital H

Hospital J

X-ray system	GE Prestilix 1600	
	kVp	CF = DAP_{ref}/DAP_{hosp}
Without table		1.10

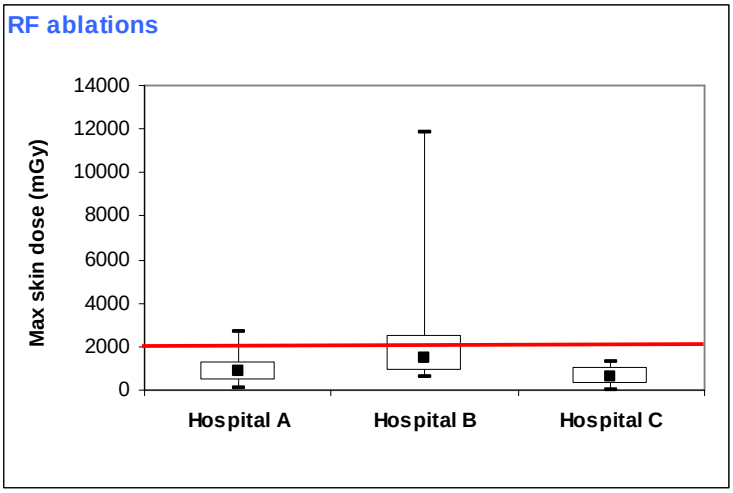
Table 10: DAP calibration factor for the system used in hospital J

Skin dose measurements

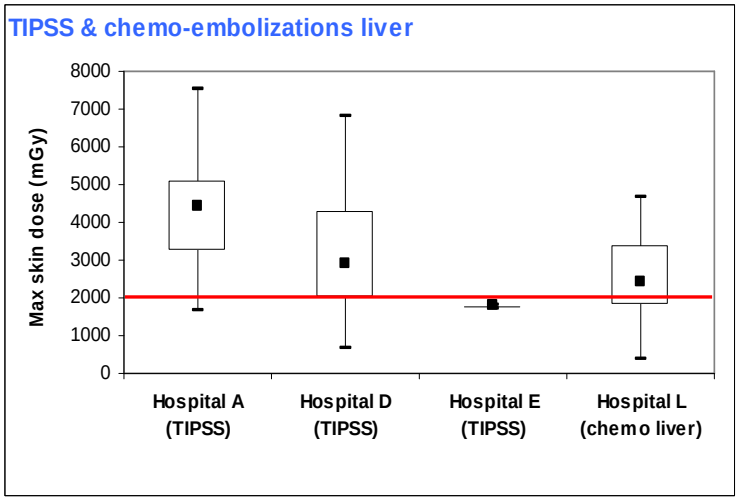
Comparison of different hospitals

In figure 7 (a to g), overviews are given of the average skin doses measured in every hospital separately for the different procedures. The figures are given in terms of boxplots, in which the minimum, 1st quartile, median, 3rd quartile and maximum are given.

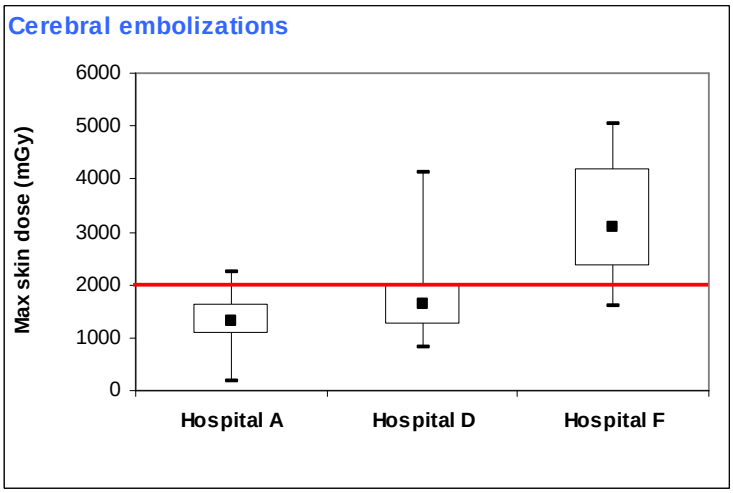
For the RF ablations (figure 7a), a dose of 12 Gy was measured for one of the patients in hospital B. The equipment in hospital B is an older system, for which it is not possible to move the position of the table. Patients are in general positioned around 50-60 cm from the focal spot. The respective patient had a weight of 140 kg and it would in this case be recommended to have moved the patient further away from the X-ray tube. At hospital B, they are aware now that this kind of system should not be used for complex interventional procedures and they decided to move to another room in the near future.


RF ablations
Max skin dose (mGy)
14000
12000
10000
8000
6000
4000
2000
0
Hospital A
Hospital B
Hospital C

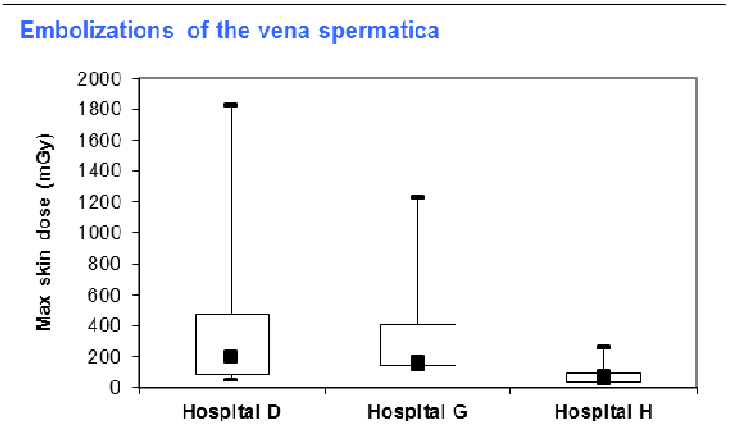
(a)


TIPSS & chemo-embolizations liver
Max skin dose (mGy)
8000
7000
6000
5000
4000
3000
2000
1000
0
Hospital A (TIPSS)
Hospital D (TIPSS)
Hospital E (TIPSS)
Hospital L (chemo liver)

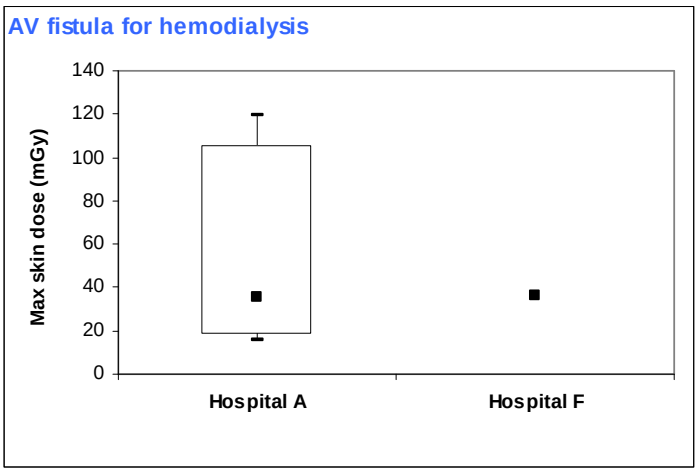
(b)


Cerebral embolizations
Max skin dose (mGy)
6000
5000
4000
3000
2000
1000
0
Hospital A
Hospital D
Hospital F

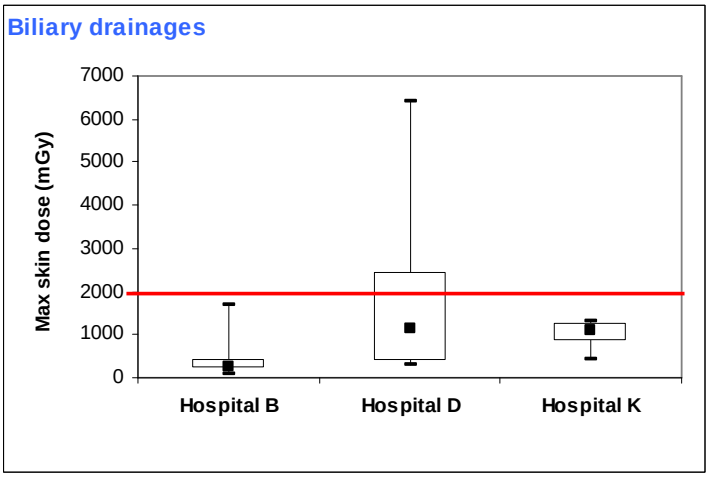
(c)


Embolizations of the vena spermatica
Max skin dose (mGy)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
Hospital D
Hospital G
Hospital H

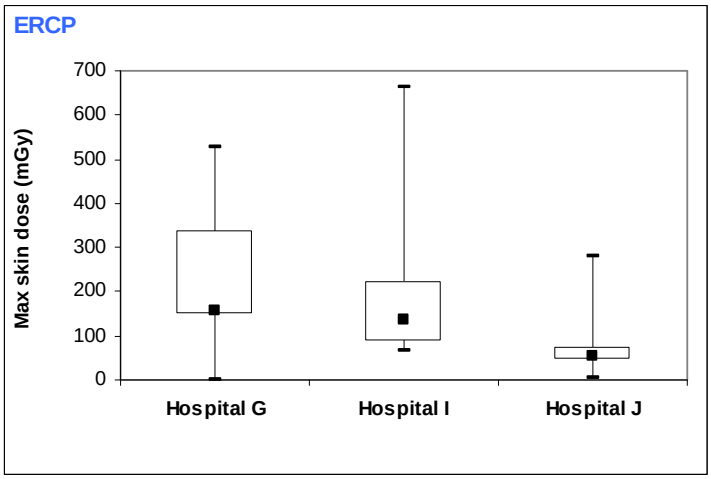
(d)


AV fistula for hemodialysis
Max skin dose (mGy)
140
120
100
80
60
40
20
0
Hospital A
Hospital F

(e)


Biliary drainages
Max skin dose (mGy)
7000
6000
5000
4000
3000
2000
1000
0
Hospital B
Hospital D
Hospital K

(f)



(g)

Figure 7: Overview of the measured maximum skin doses for every procedure in every contributing hospital

Comparison of different procedures

In figure 8, the different procedures are compared to each other in terms of boxplots. For every procedure, the data of all patients in every contributing hospital is taken into account. For RF ablations, for 20% of the patients the dose threshold for deterministic effects to the skin (2Gy) was exceeded. For TIPS procedures 76%, for cerebral embolizations 40% and for the chemo-embolizations of the liver 50% of the patients had maximum skin doses exceeding the deterministic limit. For the biliary drainages, only 11% exceeded the limit and for the embolizations of the vena spermatica, the ERCPs and the AV fistula for hemodialysis none of the patients had skin doses larger than 2 Gy.

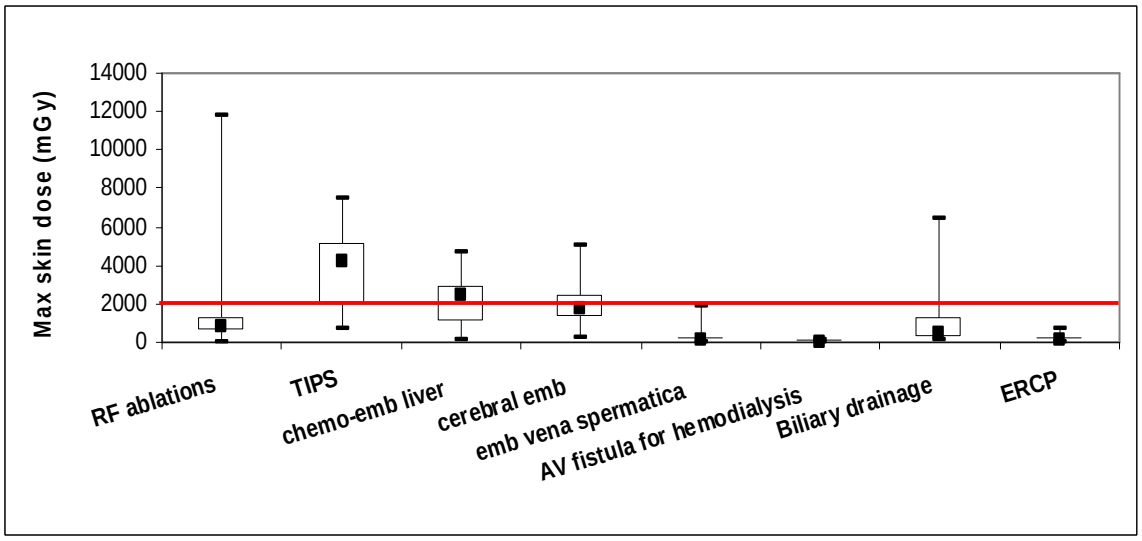


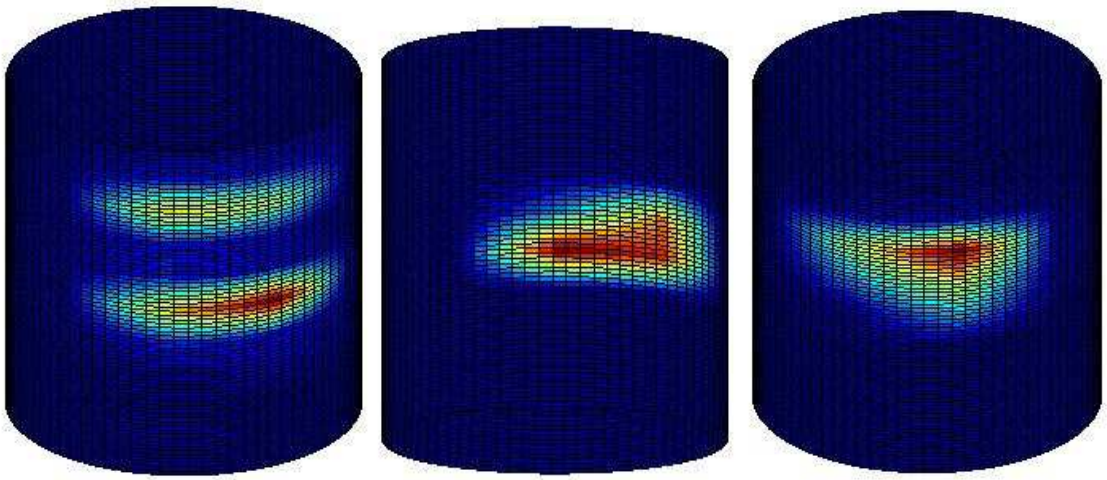
Figure 8: Comparison of the measured maximum skin doses for every procedure

Distribution of skin doses

The dose distribution on the skin of the patients is plotted in figures 9 to 13 for RF ablations, TIPS and chemo-embolizations of the liver, cerebral embolizations, embolizations of the vena spermatica and biliary drainages, respectively.

RF ablations

In figure 9, the skin dose distributions are shown for RF ablations. In hospital A, a bi-plane system is used, which can be clearly observed in figure 9a. In hospital B (figure 9b) and hosiptal C (figure 9c), a mono-plane system is used.

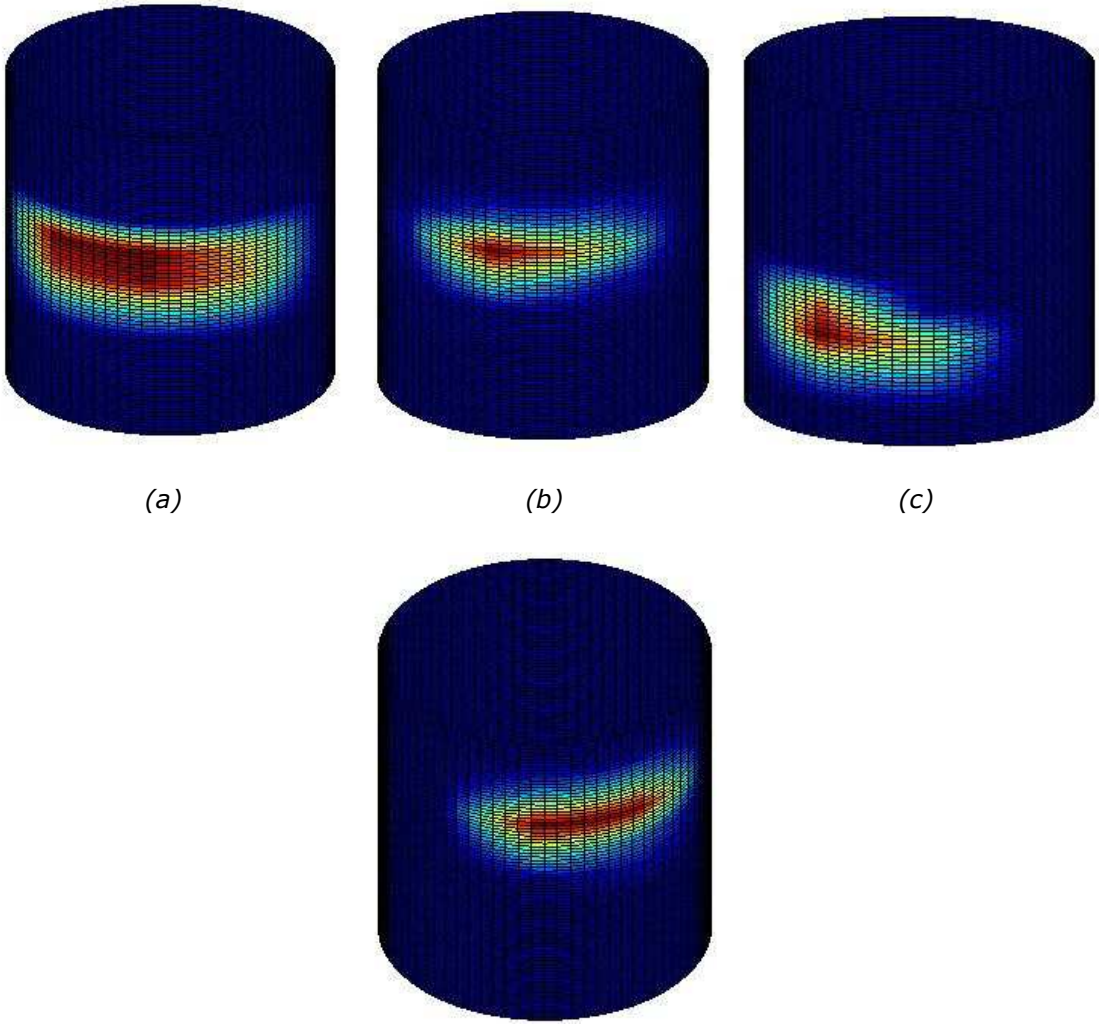


(a) *(b)* *(c)*

Figure 9: dose distributions to the skin for RF ablations in hospital A (a), hospital B (b) and hospital C (c)

TIPS and chemo-embolizations of the liver

For TIPS and chemo-embolizations of the liver mono-plane systems were used in all hospital. From the dose mappings in figure 10 it can also been seen that the tube does not vary a lot during the procedure. One clear dose hot spot is observed for the TIPS procedures in hospital A (figure 10a), Hospital D (figure 10b) and hospital E (figure 10c) and for the chemo-embolizations of the liver in hospital L (figure 10d). This explains why skin doses for these procedures can be so high.



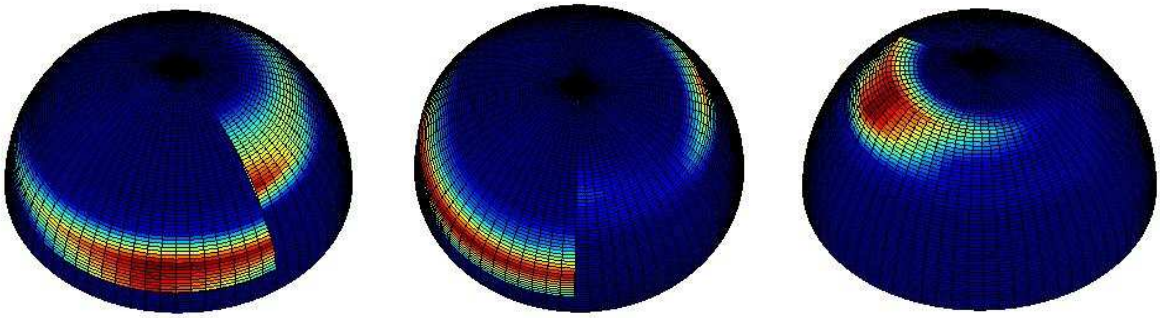
(a) *(b)* *(c)*

(d)

Figure 10: dose distributions to the skin for TIPS in hospital A (a), hospital D (b) and hospital E (c) and for chemo-embolizations of the liver in hospital L (d)

cerebral embolizations

In hospital A and D a bi-plane system is used for the cerebral embolizations, while hospital F uses a mono-plane sytem. However, from the detailed dose information that was available for both tubes separately in hospital D, it was noted that the contribution of the second tube on the total DAP was on average only 14%. This can also be observed in the dosemapping in figure 11b, where the second dose spot is much smaller and not so bright as the first spot. On the other hand, for several patients in hospital A two bright spots with higher doses could be observed in the skin dose distribution (figure 11a). In figure 11c, the dose distribution on the head of the patient is shown for the mono-plane system in hospital F

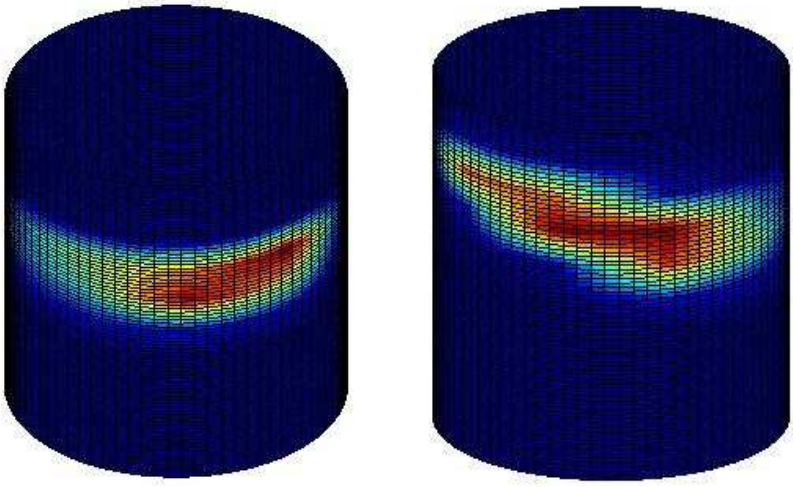


(a) *(b)* *(c)*

Figure 11: dose distributions to the skin for cerebral embolizations in hospital A (a), hospital D (b) and hospital F (c)

Embolizations of the vena spermatica

Embolizations of the vena spermatica are most of the time performed on stationary X-ray systems, which means that the X-ray tube can not vary as much as is the case with a C-arm system used for most interventional procedures. This is again clearly seen in the dose mappings in figure 12a and b for hospital G and H, respectively. We can see that the X-ray field is quite large for this procedure in both hospitals. There is no skin dose distribution available from the measurement data in hospital D, as they come from another project.

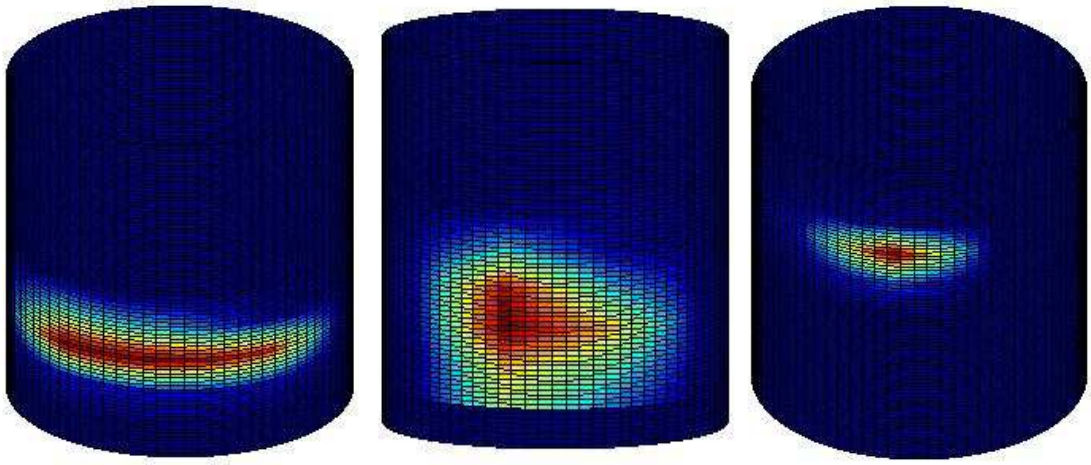


(a) *(b)*

Figure 12: dose distributions to the skin for embolizations of the vena spermatica in hospital G (a) and hospital H (b)

Biliary drainages

In figure 13, the skin dose distribution for biliary drainages is shown for the conventional procedure in hospital B (figure 13a), and a PTC procedure in hospital D (figure 13b) and hospital K (figure 13c). There is a clear difference in field size and field shape between the hospitals.

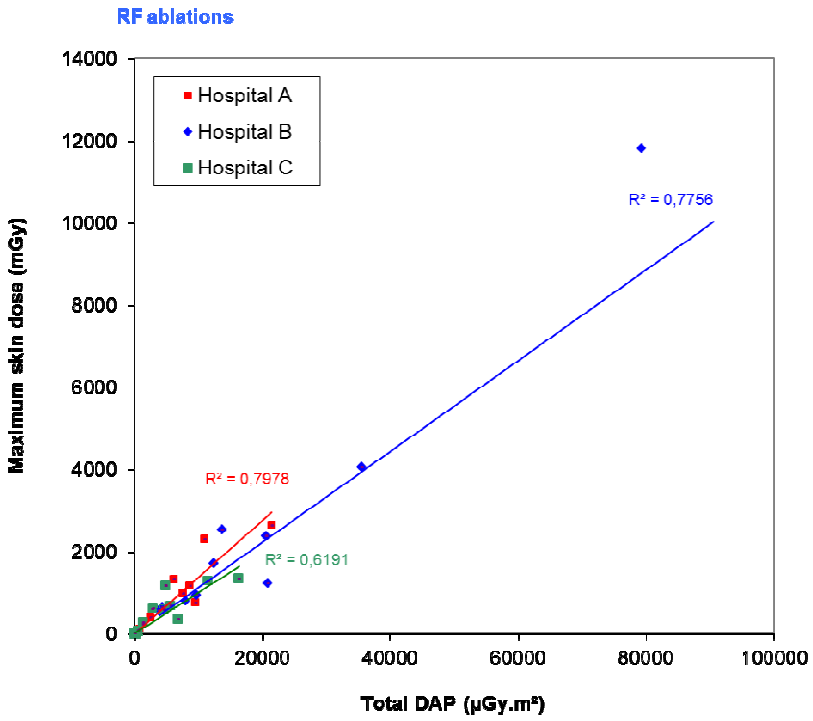


(a) *(b)* *(c)*

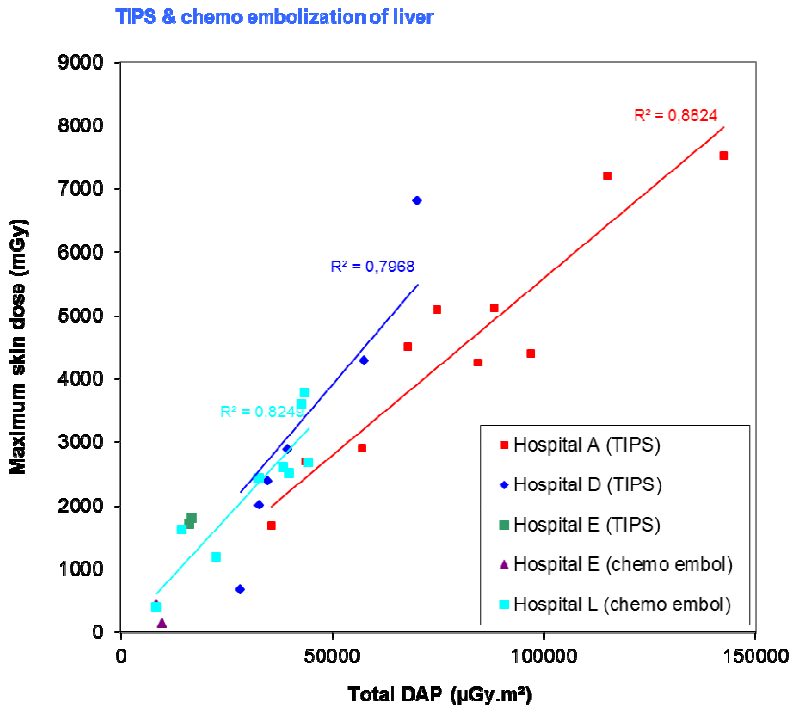
Figure 13: dose distributions to the skin for biliary drainages in hospital B (a), hospital D (b) and hospital K (c)

Correlation between measured maximum skin doses and DAP

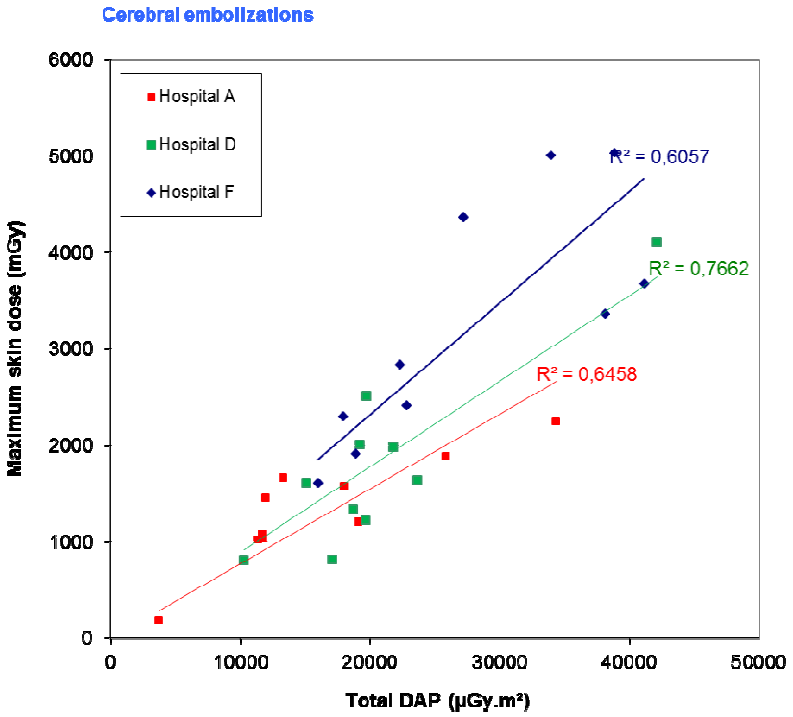
In figures 14 (a to g), the correlation between the maximum measured skin dose and the total DAP-value is given separately for every contributing hospital for every procedure.
In figure 14b, the correlation is illustrated for the TIPS procedure and the chemo-embolization of the liver. As the same region of the patient is irradiated, we are interested to see if similar correlation between maximum skin dose and total DAP can be observed for both procedures.



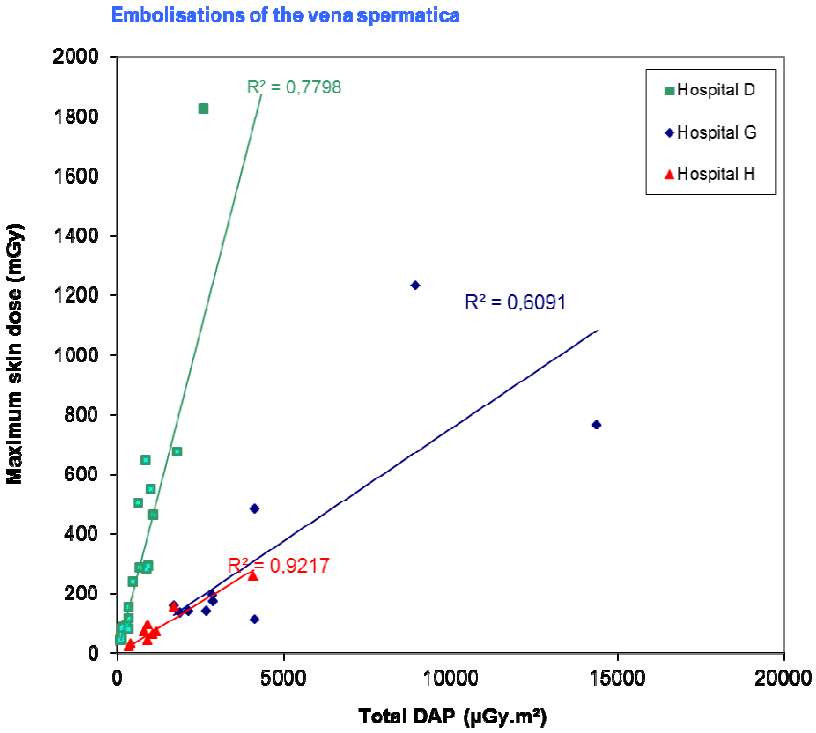
(a)


TIPS & chemo embolization of liver
Maximum skin dose (mGy)
Total DAP (µGy.m²)
R² = 0,8524
R² = 0,7968
R² = 0,8245
Hospital A (TIPS)
Hospital D (TIPS)
Hospital E (TIPS)
Hospital E (chemo embol)
Hospital L (chemo embol)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
0
50000
100000
150000

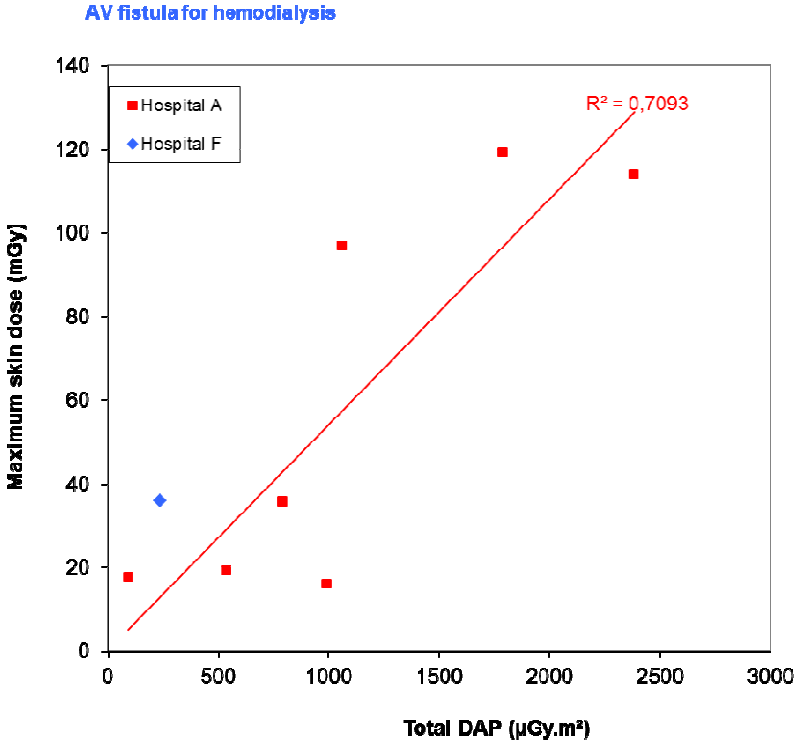
(b)


Cerebral embolizations
Maximum skin dose (mGy)
Total DAP (µGy.m²)
Hospital A
Hospital D
Hospital F
R² = 0,6057
R² = 0,7662
R² = 0,6458
0
1000
2000
3000
4000
5000
6000
0
10000
20000
30000
40000
50000

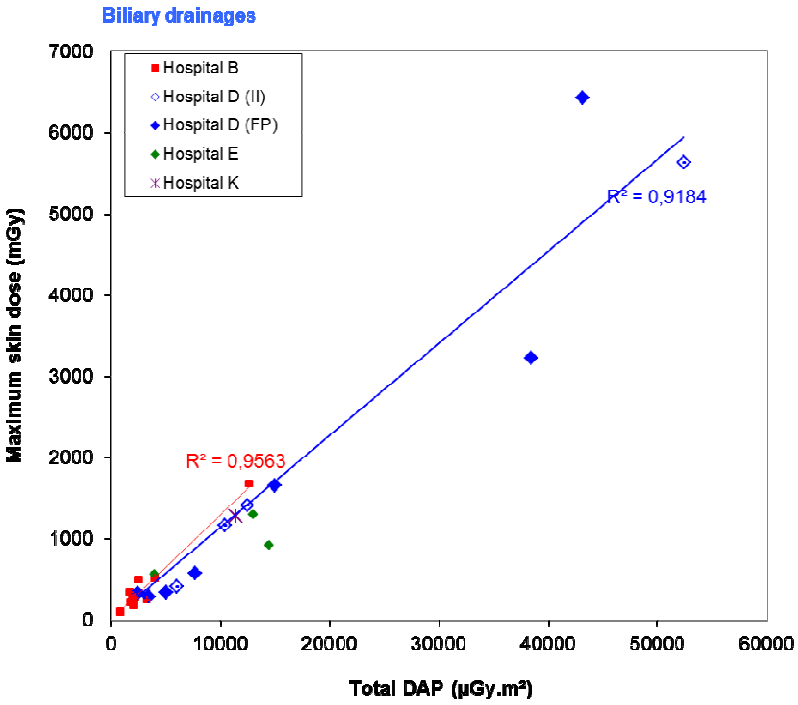
(c)


Embolisations of the vena spermatica
Maximum skin dose (mGy)
Total DAP (µGy.m²)
R² = 0,7798
R² = 0,6091
R² = 0,9217
Hospital D
Hospital G
Hospital H
0
200
400
600
800
1000
1200
1400
1600
1800
2000
0
5000
10000
15000
20000

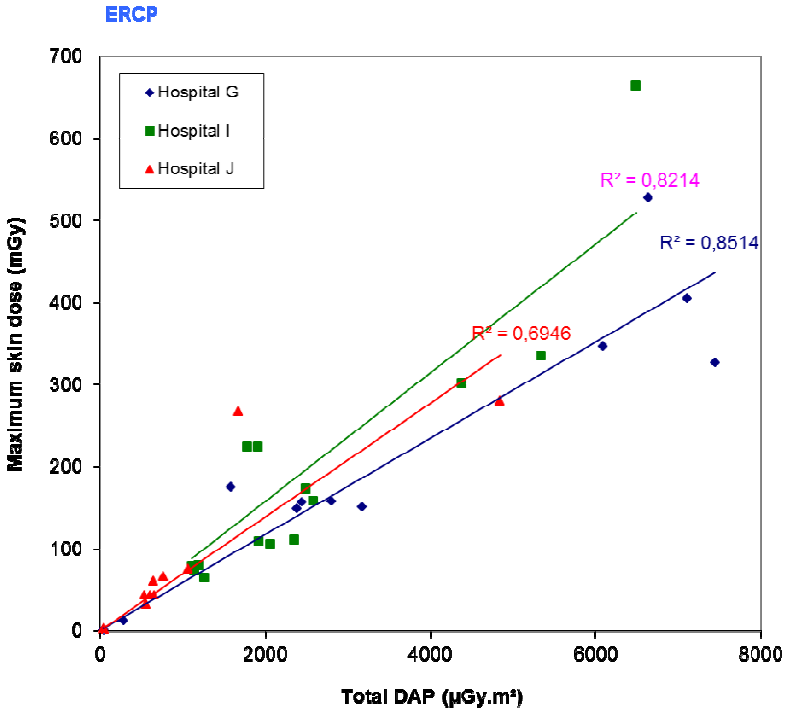
(d)


AV fistula for hemodialysis
Maximum skin dose (mGy)
Total DAP (µGy.m²)
R² = 0,7093
Hospital A
Hospital F
0
20
40
60
80
100
120
140
0
500
1000
1500
2000
2500
3000

(e)



(f)



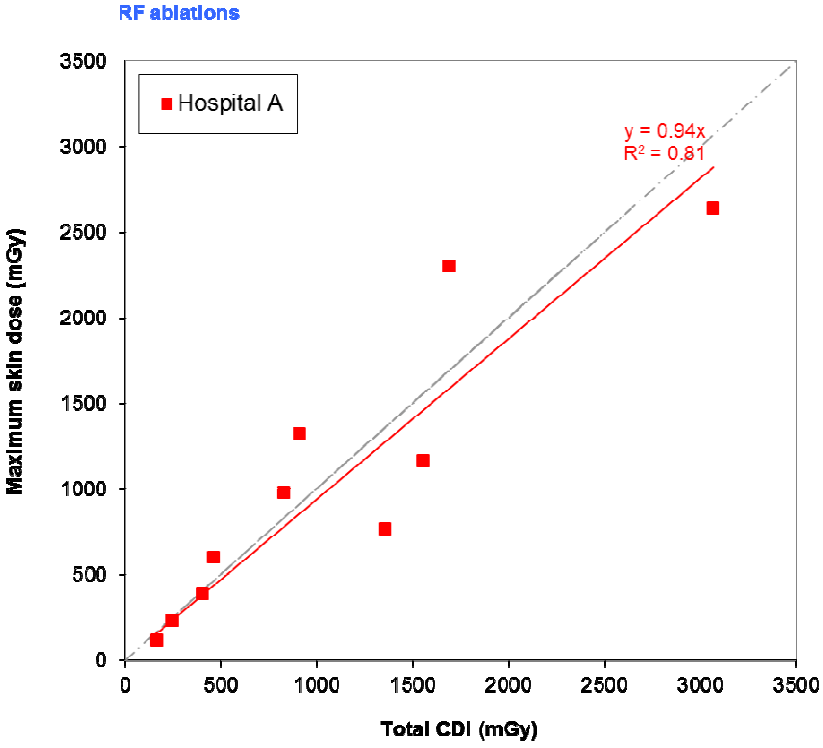
(g)

Figure 14: Correlation between the maximum skin doses and the total DAP-value for every procedure

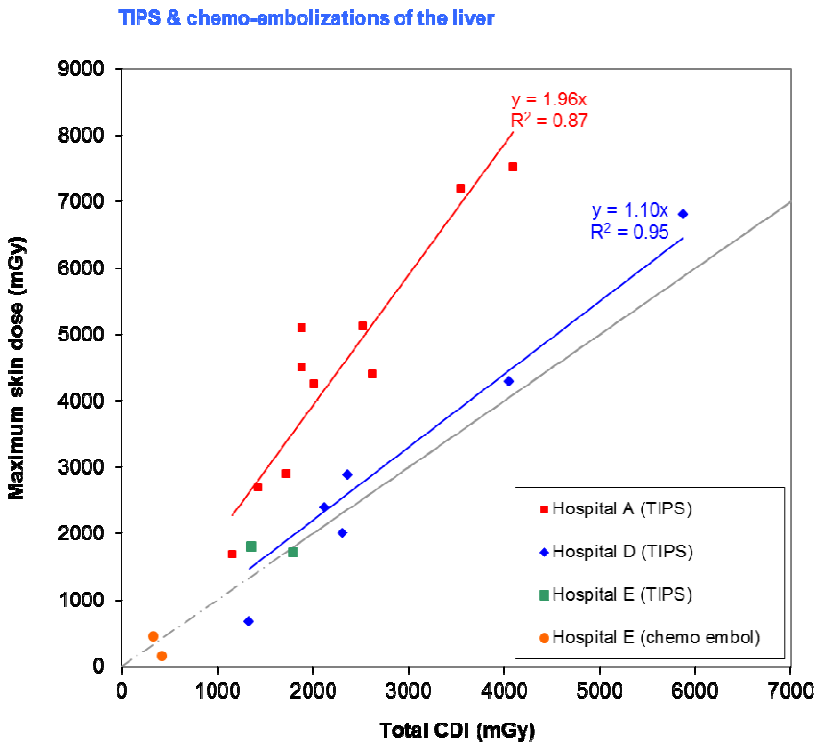
Correlation between measured maximum skin doses and CDI

In figures 15 (a to f), the correlation between the maximum measured skin dose and the total CDI-value is given for all procedures, but only for those hospitals where the CDI-value is displayed on the equipment. For the ERCP procedure, no CDI values could be collected.

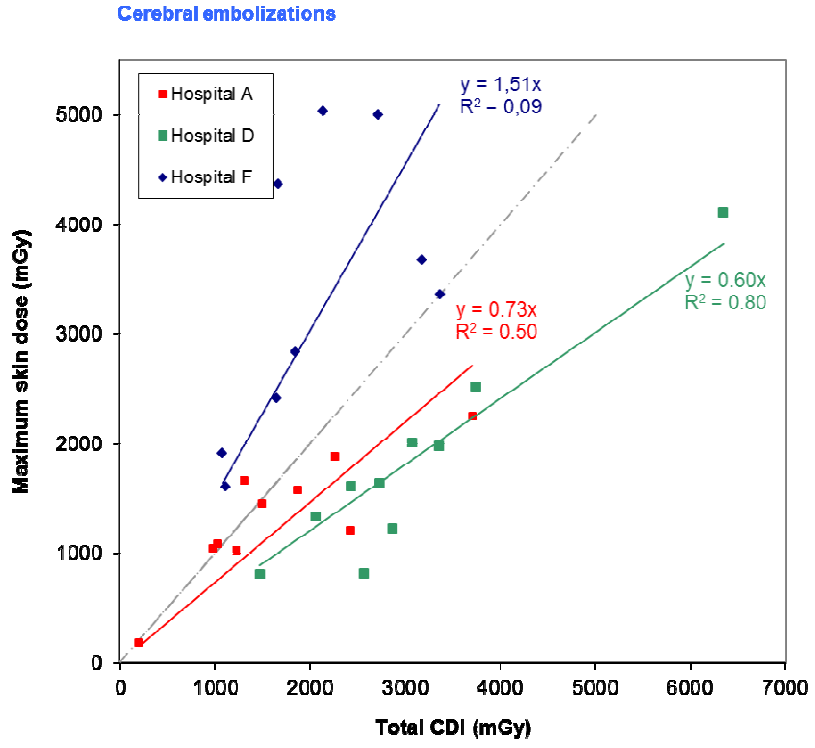
From the figures you can also clearly observe that in many cases, the CDI value does not represent the actual maximum skin dose. In some cases, it overestimates and in other cases it underestimates the maximum skin dose on the patient. Only for RF ablations and AV fistula for hemodialyses in hospital A, TIPS in hospital D and the biliary drainages performed on the x-ray system with image intensifier in hospital D, the CDI-value corresponds well with the maximum skin dose.



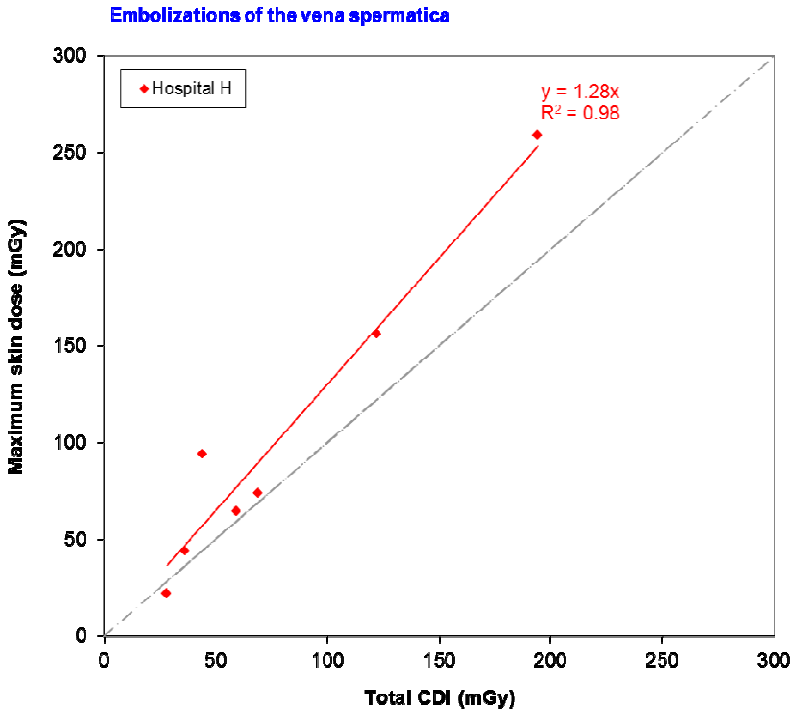
(a)


TIPS & chemo-embolizations of the liver
y = 1.96x
R² = 0.87
y = 1.10x
R² = 0.95
Hospital A (TIPS)
Hospital D (TIPS)
Hospital E (TIPS)
Hospital E (chemo embol)
Maximum skin dose (mGy)
Total CDI (mGy)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000

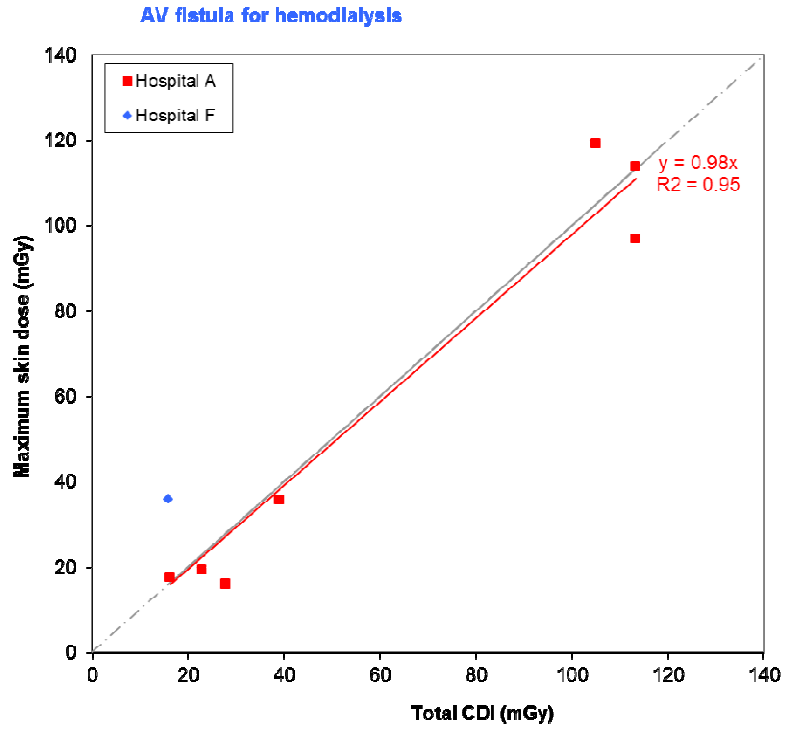
(b)


Cerebral embolizations
Hospital A
Hospital D
Hospital F
y = 1,51x
R² – 0,09
y = 0.73x
R² = 0.50
y = 0.60x
R² = 0.80
Maximum skin dose (mGy)
Total CDI (mGy)
0
1000
2000
3000
4000
5000
6000
7000

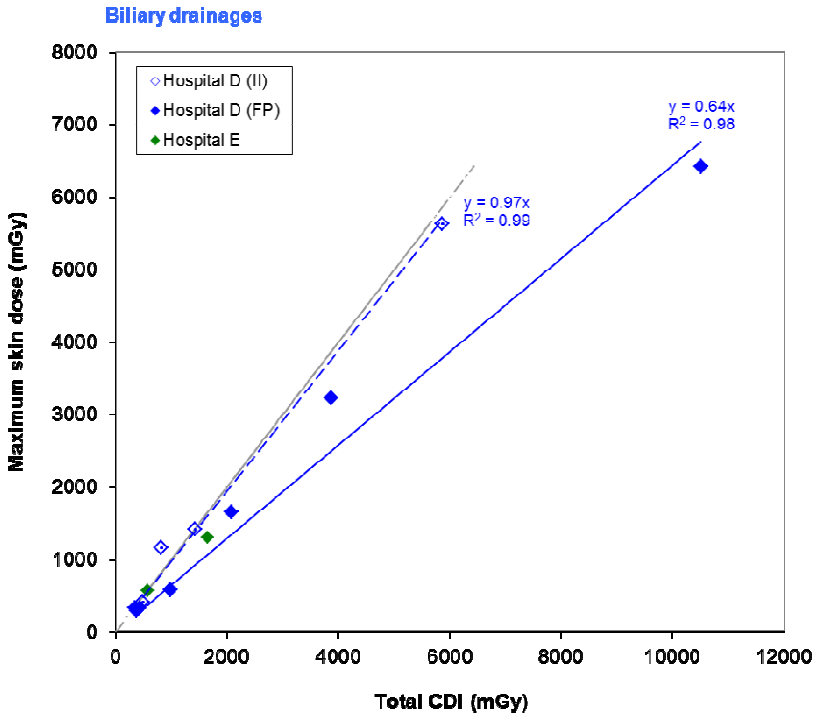
(c)


Embolizations of the vena spermatica
Hospital H
y = 1.28x
R² = 0.98
Maximum skin dose (mGy)
Total CDI (mGy)
0
50
100
150
200
250
300

(d)


AV fistula for hemodialysis
Hospital A
Hospital F
y = 0.98x
R2 = 0.95
Maximum skin dose (mGy)
Total CDI (mGy)
0
20
40
60
80
100
120
140

(e)

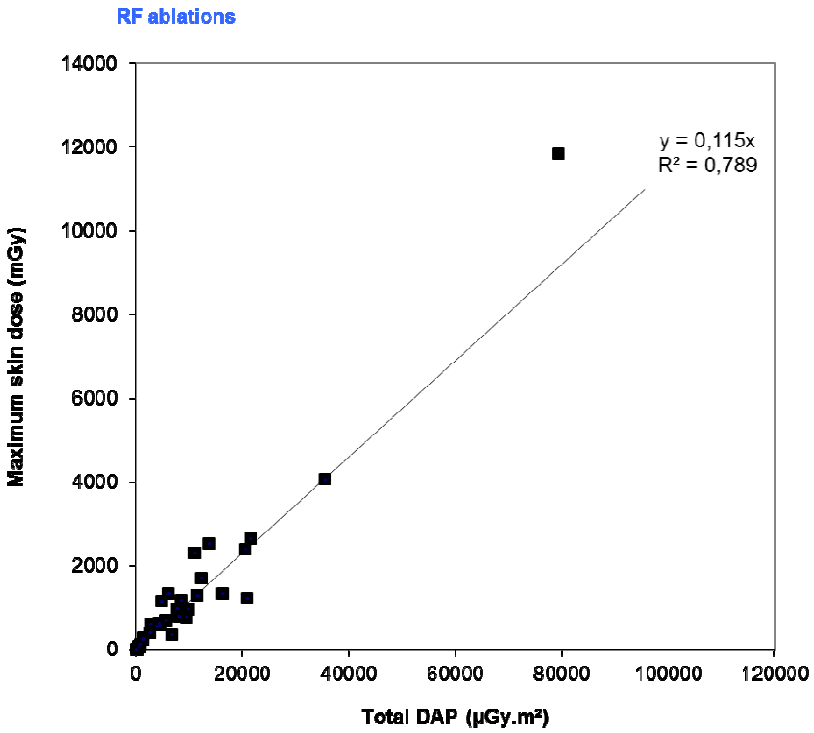


(f)

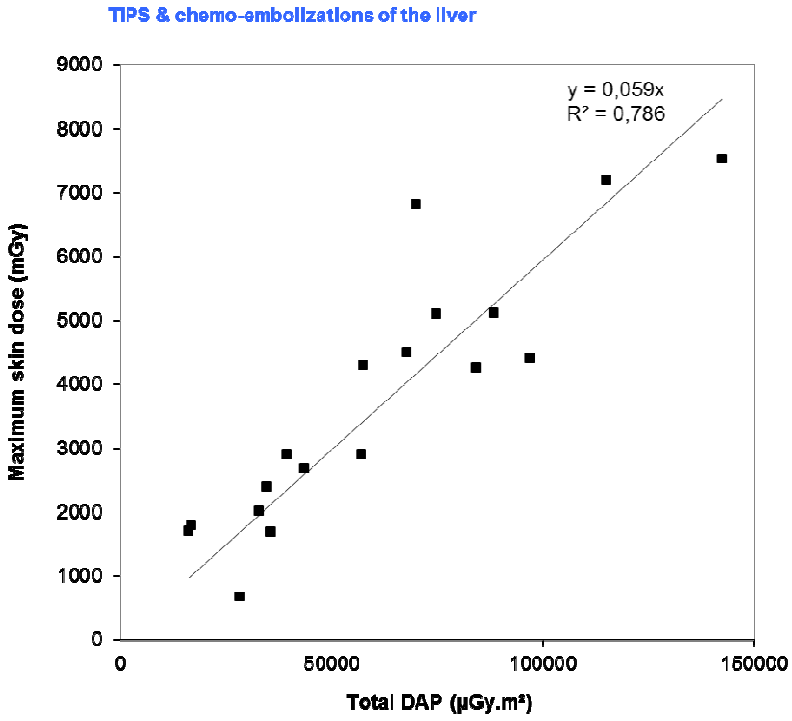
Figure 15: Correlation between the maximum skin doses and the total CDI-value for every procedure where CDI is displayed

Determination of trigger levels

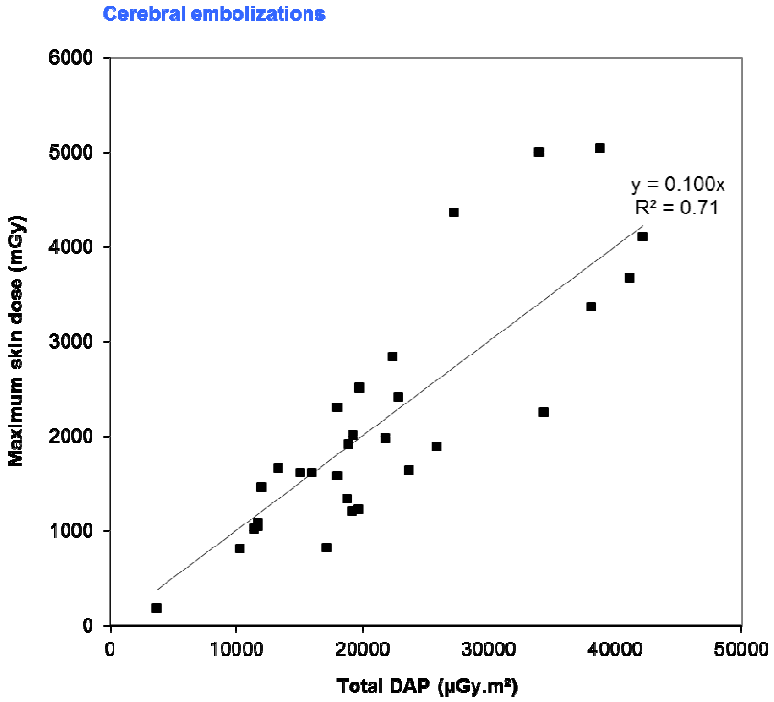
In figure 16 (a to f), the correlation between the maximum skin dose and the total DAP-value is investigated per procedure for all hospitals together. The best linear fit between the data is calculated, which will be used to calculated the DAP-value that corresponds to the deterministic limit of 2 Gy to the skin. Also a 95% confidence interval will be determined.
As for the AV fistula for haemodialysis procedure, no skin doses larger than 120 mGy are measured, it seems not useful to determine any trigger levels in terms of DAP. This procedure is further removed from the analysis.



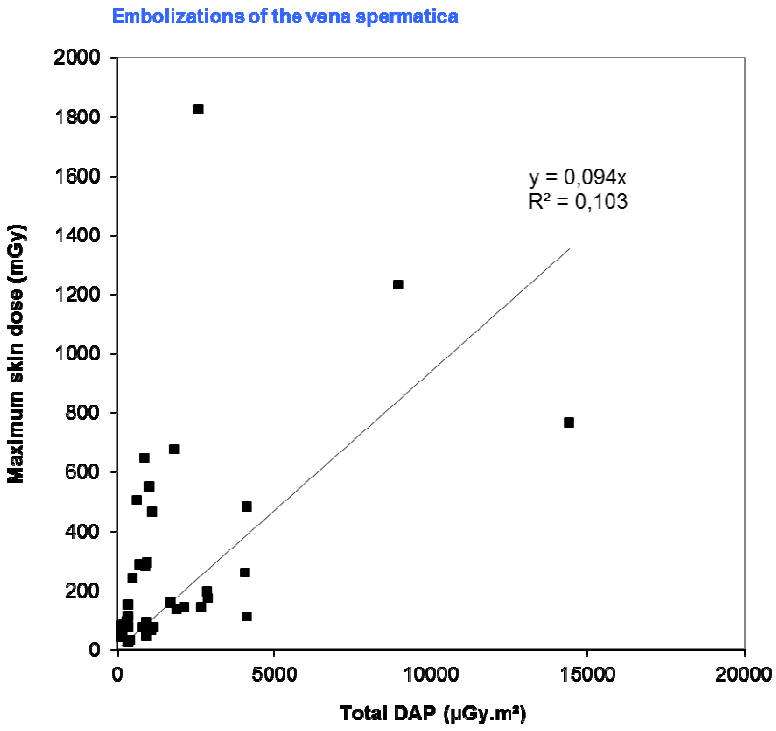
(a)


TIPS & chemo-embolizations of the liver
y = 0,059x
R² = 0,786
Maximum skin dose (mGy)
Total DAP (µGy.m²)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
0
50000
100000
150000

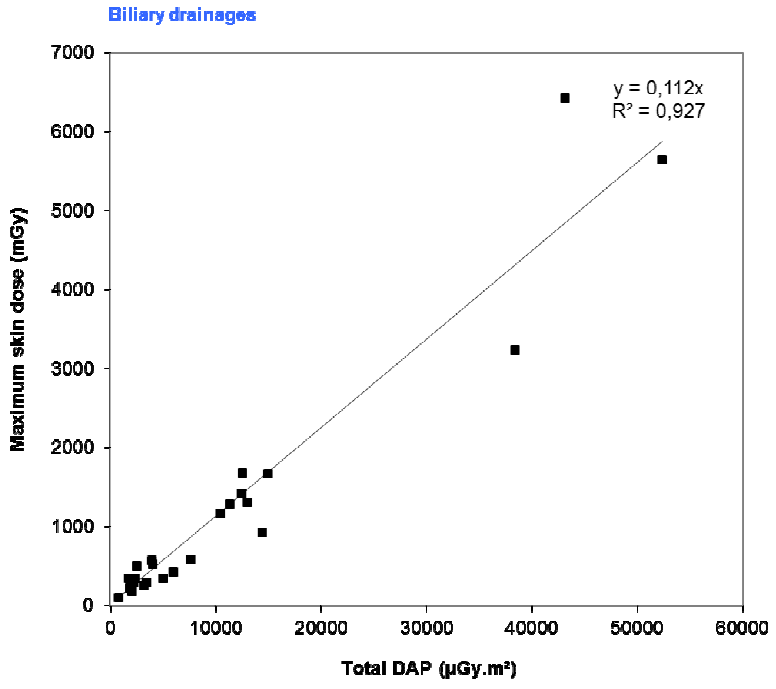
(b)


Cerebral embolizations
y = 0.100x
R² = 0.71
Maximum skin dose (mGy)
Total DAP (µGy.m²)
0
1000
2000
3000
4000
5000
6000
0
10000
20000
30000
40000
50000

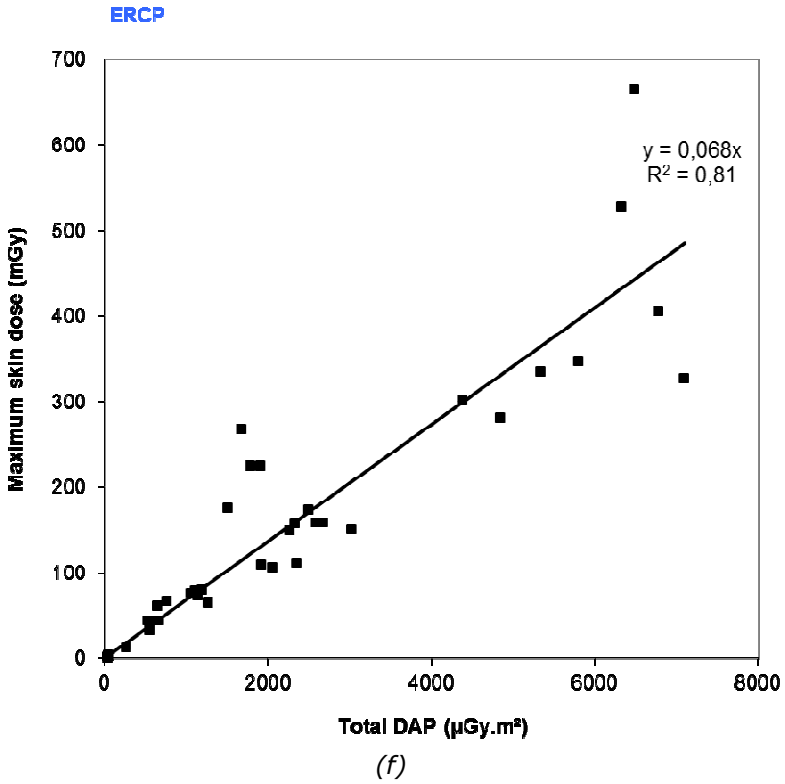
(c)


Embolizations of the vena spermatica
Maximum skin dose (mGy)
Total DAP (µGy.m²)
y = 0,094x
R² = 0,103
0
200
400
600
800
1000
1200
1400
1600
1800
2000
0
5000
10000
15000
20000

(d)


Biliary drainages
Maximum skin dose (mGy)
Total DAP (µGy.m²)
y = 0,112x
R² = 0,927
0
1000
2000
3000
4000
5000
6000
7000
0
10000
20000
30000
40000
50000
60000

(e)



(f)

Figure 16: Correlation of the maximum skin dose with the total DAP value for every procedure for all patients grouped together

In table 11, all calculated DAP-values and the 95% confidence interval are given that correspond to a maximum skin dose of 2 Gy, according to the linear fit through the data for every hospital separately (figure 14) and for all data of the hospitals together (figure 16). The deviations of the DAP-values for every hospital compared to the general DAP-value for all hospitals for a specific procedure is also given.

		Calculated DAP from linear fit (µGy.m²)	95% confidence interval (µGy.m²)	Deviation compared to general value (%)
RF ablations	Hospital A	14609	[12036 – 18580]	16
	Hospital B	18053	[14780 – 23188]	4
	Hospital C	20046	[15487 – 28408]	15
	General	**17409**	[15550 – 19771]	**-**
TIPS and chemo-embolizations of the liver	Hospital A (TIPS)	35777	[32693 – 39503]	9
	Hospital D (TIPS)	25555	[19984 – 35435]	22
	Hospital L (chemo)	27604	[24196 – 32131]	16
	General	**32878**	[30249 – 36008]	**-**
Cerebral embolizations	Hospital A	25814	[22010 – 31208]	29
	Hospital D	22529	[19253 – 27148]	13
	Hospital F	17268	[14815 – 20696]	13
	General	**19937**	[18083 – 22283]	**-**
Embolizations of the vena spermatica	Hospital D	3682	[3205 – 4326]	83
	Hospital G	26612	[19406 – 42331]	25
	Hospital H	29385	[25882 – 33986]	38
	General	**21235**	[15574 – 33362]	**-**
Biliary drainges	Hospital B	15449	[13969 – 17279]	13
	Hospital D	17633	[15322 – 20766]	1
	General	**17825**	[16327 – 19626]	**-**
ERCP	Hospital G	32510	[27988 – 38774]	11
	Hospital I	25436	[21843 – 30445]	13
	Hospital J	28783	[21756 – 42516]	2
	General	**29267**	[26508 – 32666]	**-**

Table 11: DAP-values corresponding to a maximum skin dose of 2 Gy according to a linear fit through the data for the different procedures

Discussion

Comparison with literature

In literature, the most frequent procedure for which skin doses are determined are the cerebral embolizations. In table 12, an overview is given of published data for this procedure and compared to our study. The most recent studies are selected.

The measured skin doses in this study for the cerebral embolizations are sligthly higher, but still comparable with those from literature.

	Mean max skin dose [mGy]	Range max skin dose [mGy]
This study	2147	180 - 5225
[Moritake et al ; 2008]	1800	283 - 5370
[Miller et al ; 2003]	1977	2 – 6658
[Sandborg et al ; 2009]	755	/
[D'Ercole et al ; 2007]	1160	230 – 3200
[Mooney et al ; 2000]	/	Up to 4100
[Theodorakou et al ; 2003]	/	Up to 2800
[Bethelson et al ; 1991]	/	200 - 1400

Table 12: Overview of published data on maximum skin doses to patients for cerebral embolizations

The largest published study on maximum skin doses for interventional procedures is the RAD-IR study [Miller et al ; 2003]. In table 13, the mean peak skin dose (PSD) and the [min-max] range from this study is compared to the obtained data in our study for the same procedures. The recorded skin doses in this study for the TIPS procedure, the biliary drainages and the chemo-embolizations of the liver are higher than those from the RAD-IR study. A very large difference is observed for the embolizations of the vena spermatica, but it should be mentioned that in the RAD-IR study only 1 patient was considered for this procedure.

	This study		RAD-IR study	
	Mean PSD [mGy]	(Min-Max) [mGy]	Mean PSD [mGy]	(Min-Max) [mGy]
TIPS	3770	(673 – 7516)	2168	(438 – 4644)
Biliary drainages	1155	(94 – 6424)	781	(40 – 4238)
Chemo-emb. of the liver	2140	(141 – 4676)	1380	(72 – 5471)
Emb. of the vena spermatica	275	(22 – 1823)	1199	/

Table 13: Comparison of maximum skin doses for some interventional procedures between this study and the RAD-IR study

For RF ablations, mean maximum skin doses of 1332 mGy (range: [318 – 3669 mGy]) are reported by [Taylor et al ; 2009] and of 1250 mGy by [Lickfett et al ; 2004]. This is comparable with the results in our study, with a mean maximum skin dose of 1450 mGy and a range of [8 – 11821] mGy.

Dauer et al estimated a peak skin dose for biliary drainages from 73 cases with a median value of 660 mGy and maximum of 3569 mGy. We should mention that skin dose is not measured in the study of Dauer et al, but estimated by applying a kerma-based backscatter factor for water, the ratio of mass energy-absorption coefficients for water-to-air averaged over the primary photon spectrum free in air and a conversion factor for dose to water to dose to skin [Dauer et al ; 2009]. In our study a mean

value of 1098 mGy is obtained for the biliary drainages with a maximum of 6424 mGy.
Previous skin dose measurements for cerebral embolizations have been performed in Belgium at Hospital A and Hospital G [Struelens et al; 2005]. These measurements were performed in older X-ray rooms with different X-ray systems (mono-plane configurations). In figure 17, a comparison is made between these older measurements and the new measurements from this project. The skin dose measurements in hospital A are comparable between the old and current system.

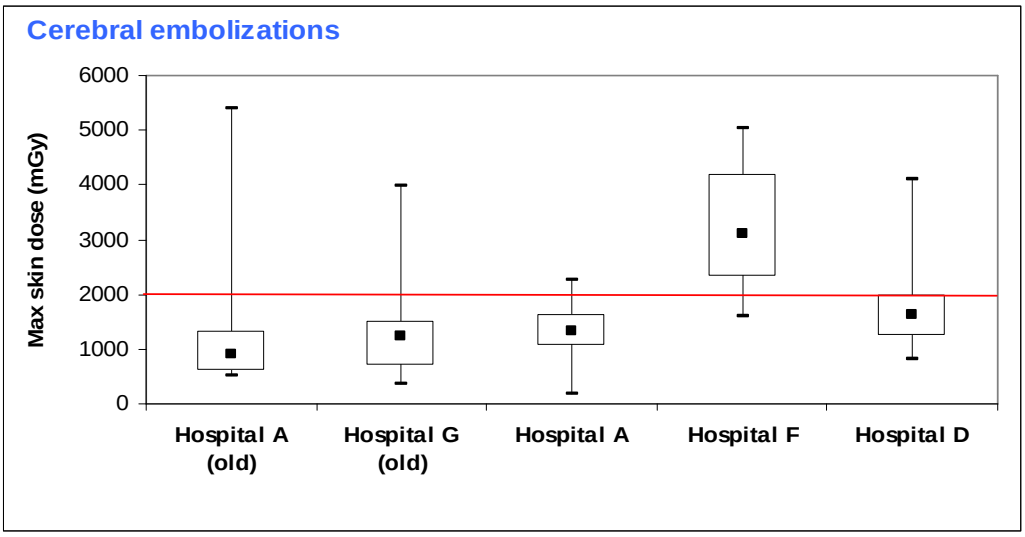


Figure 17: Comparison between maximum skin dose measurements for cerebral embolizations in old and new rooms, using different X-ray systems.

Skin-dose effects

Unlike in radiation therapy, well-defined single-dose clinical dose-response curves are not available for interventional fluoroscopy irradiations. Reports in the literature have proposed threshold doses for various specific tissue responses. Because of biological variability, the threshold dose can be quite low for the most sensitive patient relative to that for an average patient.
The pathophysiology of radiation-induced skin injury has been reviewed in detail [Hymes et al ; 2006]. Tissues at risk include the skin, hair subcutaneous fat and muscle. The expression of this injury varies and depends on a number of factors that affect the dose-response relationship and the kinetics of healing [Geleijns et al ; 2005]. Total dose, the interval between radiation exposures and the radiation field size can affect the expression and the severity of radiation injury.
Physical and patient-related factors include smoking, poor nutritional status, compromised skin integrety, obesity, overlapping skin folds and

the location of the irradiated skin [Hymes et al. ; 2006]. The anterior of the neck is the most sensitive site. The flexor surfaces of the extremities, the trunk, the back, the extensor surfaces of the extrelities, the nape of the neck, the scalp and the palms of the hands and soles of the feet are less sensitive in that order. The scalp is relatively resistant to the development of skin damage, but scalp hair epilation occurs at lower doses in comparison to hair elsewhere on the body.
Ethnic differences in skin coloration are also associated with differences in radiation sensitivity. Individuals with light-colored hair and skin are most sensitive [Balter et al ; 2010].
Defects in DNA repair genes predispose individuals to increased radiation sensitivity, which occurs in approximately 1% of the population. [Hymes et al ; 2006].
Pre-existing autoimmune and connective tissue disordes predispose patients to the development of severe radiation effects in an unpredictable fashion [Hymes et al; 2006, Benk et al; 2005, De Nayer et al; 1999, Gold et al; 2007, Lin et al; 2008 and Ross et al; 1993]. It has been suggested that concomitant administration of some medications may be a factor in sensitizing these patients [Gironet et al ; 1998].
Hyperthyroidism and diabetes mellitus are also associated with increased radiation sensitivity [Herold et al; 1999, Mettler et al; 2008 and Trott et al; 1991].
A separate form of radiation-related drug toxicity is termed *radiation-recall*. This is an inflammatory skin reaction of unknown origin that occurs in apreviously irradiated body part after drug administration [Hird et al; 2008 and Azria et al; 2005]. It may occur minutes to days after drug exposure and weeks to years after radiation exposure.

Skin dose measurements

From the results in figures 7, we can observe a very large variety in maximum skin doses for the same procedure between different hospitals but also between different patients within the same hospital.
The major factor for this large variety is the complexity of the procedure.
Other possible factors are:

- the thickness of the patient
- the type of equipment used: mono-plane or bi-plane, flat panel or image intensifier
- the amount of copper filtration that is used
- the choice of tube voltage and tube current
- the collimation of the radiation beam

For every procedure, the influence of these parameters will be investigated if the data is available.

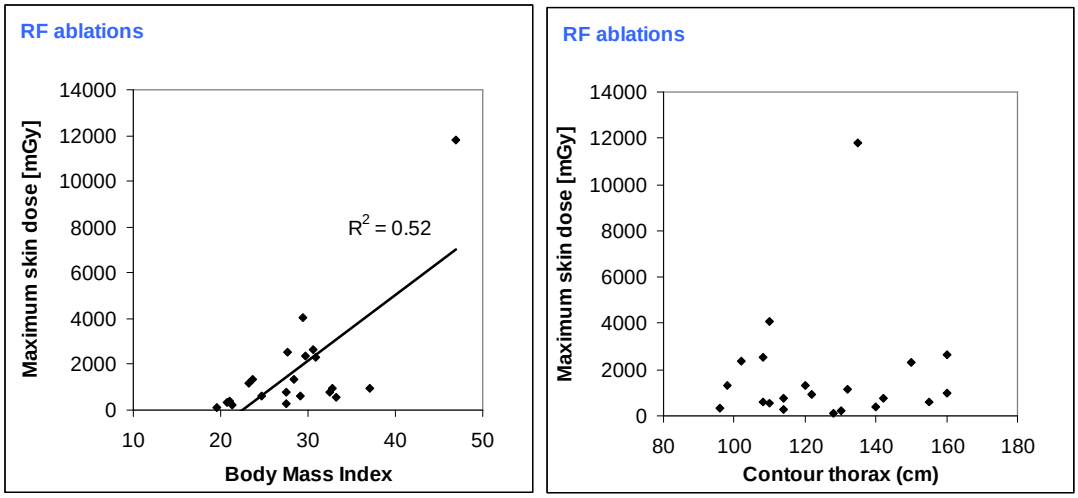
RF ablations

From figure 7a, we can observe that the skin doses at Hospital A and Hospital C are in general lower than the skin doses at Hospital B. But the difference between the mean skin doses at Hospital A, B and C is not significant (p=0.08).
For 20% (6/30) of the patients involved in this study a maximum skin dose larger than 2 Gy was observed.

The complexity of this procedure can vary significantly, depending on the number of locations that needs to be burned and the ease of reaching these locations. At Hospital C, less complex procedures (many flutter ablations) were performed, which is mainly responsible for the lower doses.

From table 1a, we can see that at Hospital A in general the fluoroscopy time is higher, as well as the number of cine frames acquired. But in this hospital a bi-plane configuration is used, which means that the dose is distributed over two tubes, irradiating different parts of the patient. Moreover, at Hospital A a flat panel detector is used, while in the other 2 hospitals the detectors are image intensifiers. At Hospital A, generally no copper filtration is used in general during cine acquisition, but no information on the use of copper filtration was available in the other hospitals.

The influence of the thickness of the patient on patient doses can be checked using the Body Mass Index (BMI) or the contour of the thorax of the patient. In figure 18a, the BMI of the patient is plotted against the maximum skin dose. A weak correlation is observed between both parameters. A similar correlation is found when BMI is plotted against total DAP-value. In figure 18b, the contour of the thorax is plotted against the maximum skin dose. No correlation can be found in these data.
The average BMIs are 26, 33 and 25 at Hospital A, B and C, respectively. The larger patients at Hospital B could partly explain the higher skin doses, but it is clear that patient thickness is not the major parameter explaining dose variations.



(a) *(b)*

Figure 18: Correlation between maximum skin dose and Body Mass Index (a) or contour of thorax (b) for RF ablations

TIPS and chemo-embolizations of the liver

From figure 7b, it is clear that skin doses are high for TIPS procedures, due to the complexity of the procedure. A large number of images is taken during the procedures (hospital A:453 ; hospital D: 334 ; hospital E: 106). Moreover, the X-ray tube stays fixed during the biggest part of the procedures. This is clearly shown in the dosemappings in Figure 10.
Doses higher than 2 Gy were measured for 78% (14/18) of the patients involved in this study.

Exposure parameters (kVp and mA) are similar in hospital A and D, but fluoroscopy time in hospital D (77 min) is higher than in hospital A (19 min). Still, skin doses in hospital D are lower than in hospital A, which can be explained by the use of copper filtration in hospital D (0.1 - 0.3 mm Cu). In hospital A no copper filtration is used during cine acquisition.

Also chemo-embolizations of the liver are high-dose procedures. Most of the measurements were performed in only 1 hospital for which 7 of the 10 patients involved, received maximum skin doses higher than 2 Gy.

Again, no correlation is found between the thickness of the patient (BMI or abdomen contour) and the maximum skin dose.

Cerebral embolizations

In figure 7c, it is shown that skin doses at Hospital F are significantly higher than at Hospital A ($p<0.001$) and Hospital D ($p=0.009$). Maximum skin doses at Hospital A and D are not significantly different ($p=0.21$). The main difference between these hospitals is while at Hospital F a monoplane system is used, a biplane is used at the 2 other hospitals.
When all patients in the 3 hospitals are considered, 40% (12/30) of them received maximum skin doses higher than 2 Gy. However, it should be mentioned that most of the patients (8/12) receiving such high doses are from hospital F where the mono-plane system is used.

The tube voltage is comparable in the 3 hospitals (mean around 80 kVp), but the selected tube current at Hospital F is higher (mean of 417 mA) compared to Hospital A (mean of 187 mA) and Hospital D (mean of 302 mA) (table 1c).

As the head of the patient is irradiated for this procedure, the influence of the thickness of the patient is irrelevant.

Also for this procedure, the complexity can vary significantly from one patient to another, depending on how easy the aneurism can be reached and how large it is.

Embolizations of the vena spermatica

From figure 7d, we can observe that skin doses at Hospital H are significantly lower than those at Hospital G ($p=0.04$). A clear difference is also observed between Hospital H and Hospital D, but it is not significant ($p=0.09$) at a 95% confidence interval. The skin doses in Hospital D and G are comparable ($p=0.82$). From table 1d, we can see that the mean fluoroscopy time at Hospital H (7 min) is lower than the fluoroscopy time at Hospital G (19 min) and Hospital D (24 min). Also less images are taken at Hospital H (4) compared to the other 2 hospitals (Hospital G: 12 ; Hospital D: 14). All three hospitals, use similar equipment with an over-couch tube configuration.

No patients were registered with maximum skin doses higher than 2 Gy. In general, skin doses are well below the deterministic limit for skin injury, but occasionnaly high skin doses can be obtained in special complex cases. This can be observed for 1 patient at hospital D and G, where maximum skin doses of 1.2 Gy and 1.8 Gy, respectively are obtained.

The average BMI is similar at Hospital G (BMI=18) and Hospital D (BMI=21). But again no correlation is observed between the BMI and the maximum skin dose or the total DAP.

Biliary drainages

The maximum skin doses in hospital D are significantly higher than those in hospital B (p=0.03). Two different types of biliary drainages are performed in both hospitals. In hospital B a more conventional and less complex procedure is performed, where the bile is drained through a tube insterted through the mouth. In hospital D and K a more complex procedure is performed, also called a percutaneous transhepatic cholangiography (PTC). A thin needle is inserted through the skin and through the liver into a bile duct. In 1 case the bile duct was also dilatated and in another case a stent was placed.
For the conventional procedures, doses stay in general well below the deterministic limit of 2 Gy. For the PTC procedures, however, 20% (3/12) of the patients involved in the study received doses higher than 2 Gy.

Much more acquisitions are made for PTC procedures (hospital E: 43 ; hospital D:129) compared to the conventional procedure (hospital B: 4).
All procedures are performed with a mono-plane configuration. In hospital D part of the procedures is performed on a system with image intensifier, while the other part was performed with a flat panel detector. However, no significant difference in dose was observed for both types of detectors.
In hospital B, the procedures are performed on a tube-above configuration.
In hospital D and E, copper filtration is used (0.1 – 0.3 mm Cu) for the complex PTC procedures.

As for all other procedures, no correlation is observed to the patient thickness.

ERCP

The mean maximum skin doses for the procedures in Hospital J are significantly lower than those at Hospital G (p=0.02), but not significant lower (at 95% confidence interval) than those at Hospital I (p=0.09). Mean skin doses at Hospital G and Hospital I are comparable (p=0.69). Fluoroscopy times at Hospital J are lower than those at Hospital I and a larger amount of copper is used (0.5 mm Cu).

In general, skin doses for this procedure are well below the deterministic limit for skin injury. From our data, we can see that maximum skin doses not even reach a dose of 1 Gy.

Again, no correlation is observed between BMI and maximum skin dose or total DAP. The mean BMI value at Hospital J and Hospital I are the same (BMI = 26). No patient data was available for the measurements at Hospital G.

Determination of trigger levels

For the RF ablations, TIPS and chemo-embolizations, biliary drainages and ERCP procedures a significant linear correlation ($p<0.001$) was observed for each procedure between maximum skin dose and total DAP-value for all patients of the 3 hospitals. From table 11, we could also observe that the differences between the hospital specific trigger levels and the general trigger level are small.
This means that one general trigger level could be determined for each of these procedures. The calculated DAP-values from the linear fit through the data in table 11 are rounded and set as trigger levels for these procedures in table 14.

	Trigger level in terms of DAP (µGy.m²)	95% confidence interval (µGy.m²)
RF ablations	18000	[16000 – 20000]
TIPS & chemo-emb. of the liver	33000	[30000 - 36000]
Biliary drainages	18000	[16500 – 20000]
ERCP	29500	[27000 – 33000]

Table 14: Trigger levels in terms of DAP for RF ablations, TIPS & chemo-embolizations of the liver, biliary drainages and ERCPs

RF ablations

Although hospital A used a bi-plane system, while the other 2 hospitals used a mono-plane X-ray machine, one of the tubes is used more frequent than the other. This explains why the correlation between total DAP and maximum skin dose is quite similar for all 3 hospitals (figure 14a).
The mean difference between the measured maximum skin dose and the calculated maximum skin dose from the linear fit is 29%.

TIPS and chemo-embolizations of the liver

All contributing hospitals for these procedures used mono-plane X-ray systems. As well flat panel detectors as image intensifiers are included.
The mean difference between the measured maximum skin dose and the calculated maximum skin dose from the linear fit is 25%.

Biliary drainages

At Hospital B conventional biliary drainage procedures are performed with access through the mouth, while in the other hospitals (hospital D and K) PTC procedures are performed with percutaneous access.
As the correlation between total DAP and maximum skin dose seems not very different for both types of procedures, one trigger level was determined. The mean difference between the measured maximum skin dose and the calculated maximum skin dose from the general linear fit is 24%.

We could also determine a trigger level for both types of procedure separately (table 15).
The mean difference between the measured maximum skin dose and the calculated maximum skin dose from the linear fit for the conventional procedure is 23%. The mean difference between measured and calculated MSD from the linear fit for the PTC procedure is 24%.

	Access	Trigger level in terms of DAP (µGy.m²)	95% confidence interval (µGy.m²)
Biliary drainages	conventional	16000	[14000 – 17500]
	PTC	18000	[16000 – 21000]

Table 15: Trigger levels in terms of DAP for 2 types of biliary drainages

ERCP

All contributing hospitals for these procedures used mono-plane X-ray systems. Hospital J and hospital I used a tube-above-table configuration, while the system in hospital G was a tube-under-table configuration. This had no significant influence on the correlation between total DAP and maximum skin dose. The position of the X-ray tube does not vary much during the procedure. The mean difference between the measured maximum skin dose and the calculated maximum skin dose from the general linear fit is 26%.

For the cerebral embolizations and the embolizations of the vena spermatica procedures, the deviations between the hospital specific calculated DAP-value and the general calculated DAP-value are larger.

Cerebral embolizations

In general, the correlations between total DAP and maximum skin dose for every hospital separately is less good (figure 14c), because there is a lot of variation in tube orientation during the procedure.
Moreover, there is a difference in system configuration between the hospitals. While in hospital A and D a bi-plane system is used, a mono-plane system is used in hospital F. For a bi-plane system the total DAP is distributed over 2 tubes, which changes of course the correlation with maximum skin dose compared to a monoplane system. However, it should be mentioned that in hospital D, the lateral tube is used less frequently (only 14% of total dose) than the frontal tube. For the bi-plane system in hospital A, we do not have this information.
Therefore, we determined a separate trigger level for both systems. The correlations for both types of systems are illustrated in figure 19 and the corresponding trigger levels are given in table 16.

The mean difference between the measured maximum skin dose and the calculated maximum skin dose from the general linear fit is 18% and 23% for the mono-plane and bi-plane system, respectively.

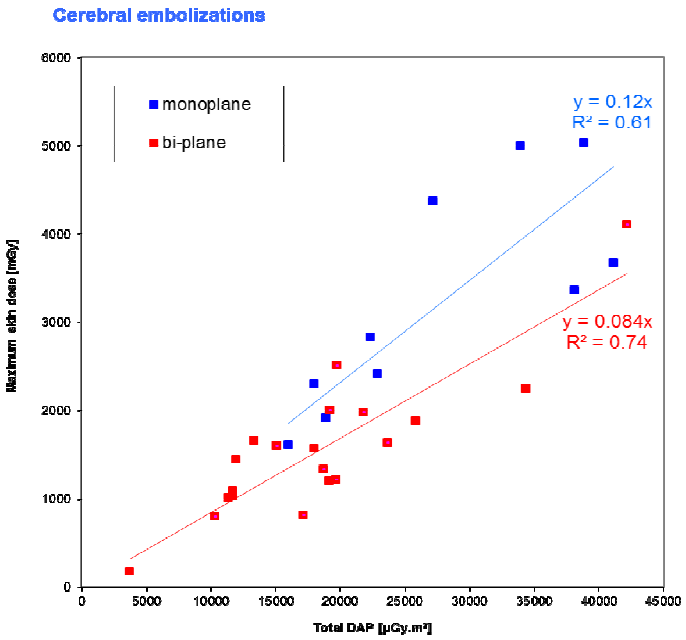


Figure 19: Correlation of the maximum skin dose with the total DAP value for cerebral embolizations with mono-plane and bi-plane X-ray systems

	System configuration	Trigger level in terms of DAP (µGy.m²)	95% confidence interval (µGy.m²)
Cerebral embolizations	Mono-plane	17500	[15000 – 21000]
	Bi-plane	24000	[21500 – 27000]

Table 16: Trigger levels in terms of DAP for cerebral embolizations, separately for mono-plane and bi-plane X-ray systems

These trigger levels are much lower than some found in literature. Sandborg et al determined trigger levels of 61200 µGy.m² and D'Ercole et al of 70000 µGy.m².
Also the trigger levels determined for the measurements in 2005 at Hospital A and G (35000 µGy.m²) are higher than those determined in this project.

Embolizations of vena spermatica

For the embolizations of the vena spermatica, there is a large difference in correlation for hospital D compared to hospitals G and H. However, similar kind of systems is used for all 3 hospitals (fixed system with over-couch tube configuration). One possible explanation is that in hospital D the radiation field is extremely collimated compared to the 2 other hospitals. This has a large influence on the DAP-value, but not on the maximum skin dose measured. From the skin dose distributions in figure 12, we could observe that radiation field sizes are large in hospital G and H. Therefore, the assumption of a smaller collimation in hospital D seems reasonable.

In figure 20, the correlation between maximum skin dose and total DAP is shown for the data from Hospital G and H and a corresponding **trigger level of 27000 µGy.m²** is set.
The mean difference between the measured maximum skin dose and the calculated maximum skin dose from the general linear fit is 25%.

However, this trigger level should not be used when highly collimated fields are used. We should mention, however, that this procedure is not critical in terms of deterministic skin damage.

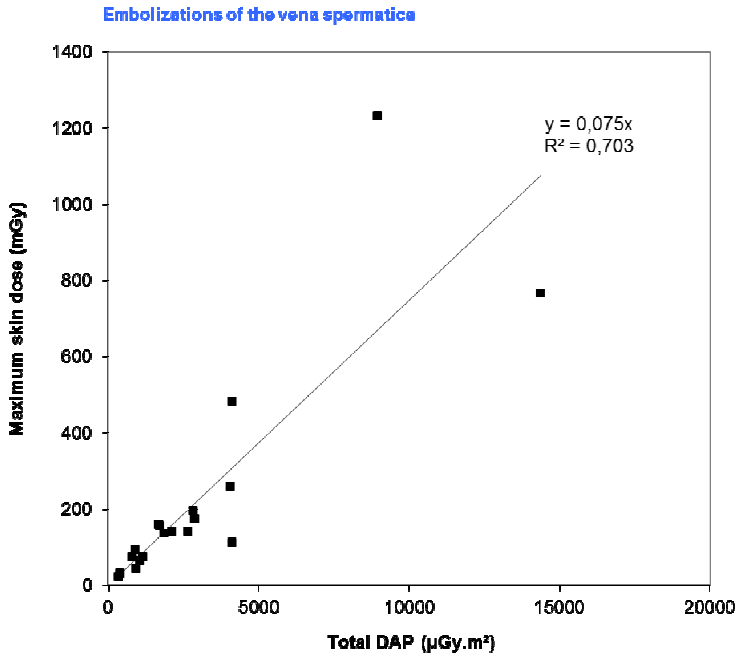


Figure 20: Correlation of the maximum skin dose with the total DAP value for the embolizations of the vena spermatica for Hospital G and H

DAP calibrations

As stated above, all DAP-meters in the project are calibrated and all DAP-values are corrected in accordance to the corresponding DAP calibration factor. The importance of DAP calibration is illustrated by comparing the trigger levels between the non-corrected and corrected DAP data for cerebral embolizations (table 17). Deviations up to almost 30% were found.

This emphasizes the fact that the determined trigger levels in this project can only be used in practice for calibrated DAP-meters.

Cerebral embolizations	Trigger levels		
	Non-corrected data	Corrected data	Difference (%)
Hospital A	29559	25814	15
Hospital D	28965	22529	29
Hospital F	13268	17268	-23
General	21544	19937	8

Table 17: Difference between trigger levels for X-ray systems with well-calibrated and badly-calibrated DAP meters

Trigger levels in practice

In view of dose optimization strategies, patient dose should be evaluated for every patient separately for high-risk procedures. For interventional procedures, the main concern is patient skin dose.
As this dose cannot be measured directly in routine practice, the use of the DAP-value is recommended.
This value should be registered in the patient file and compared to the appropriate trigger level for every patient.

If for one specific patient the trigger value is exceeded, the patient can be informed on possible skin burns and followed up more closely.
If DAP-values exceed the trigger level on a regular basis, it should be considered to evaluate the procedure method or the equipment used and perform some radiation protection measures in general.

At this moment it is not recommended to use the CDI-value as trigger level.
First of all, at this stage not all used X-ray equipment display this value. Secondly, it is not clear to the project members how this value is determined and it could be different from one manufacturer to the other. As can be seen in figure 15b for the TIPS procedures, the correllation can be different between CDI and maximum skin dose for two systems of different manufacturers.
And finally, it should also be very clear that CDI is not always an exact calculation of the maximum skin dose. From figure 15 (a-f) it could be observed that CDI in some cases over-estimates and in other cases under-estimates the maximum skin dose.

As many of the selected procedures for this project are concentrated on the abdominal region, we also investigated if 1 general trigger level could be observed for abdominal procedures performed by the interventional radiologist. Following procedures are included: TIPS, chemo-embolizations of the liver and PTC procedures. In figure 21, the linear correlation between total DAP and maximum skin dose is given and is acceptable. **A trigger level of 31000 µGy.m²** was determined with 95% confidence interval [28500 – 34500] µGy.m².
However, we should note that the use of such a general trigger level, is not as accurate as using a procedure specific trigger level. The mean difference between the measured maximum skin dose and the calculated maximum skin dose from the general abdominal linear fit is 25% for TIPS procedures, 28% for the chemo-embolization of the liver and 43% for the PTC procedure.

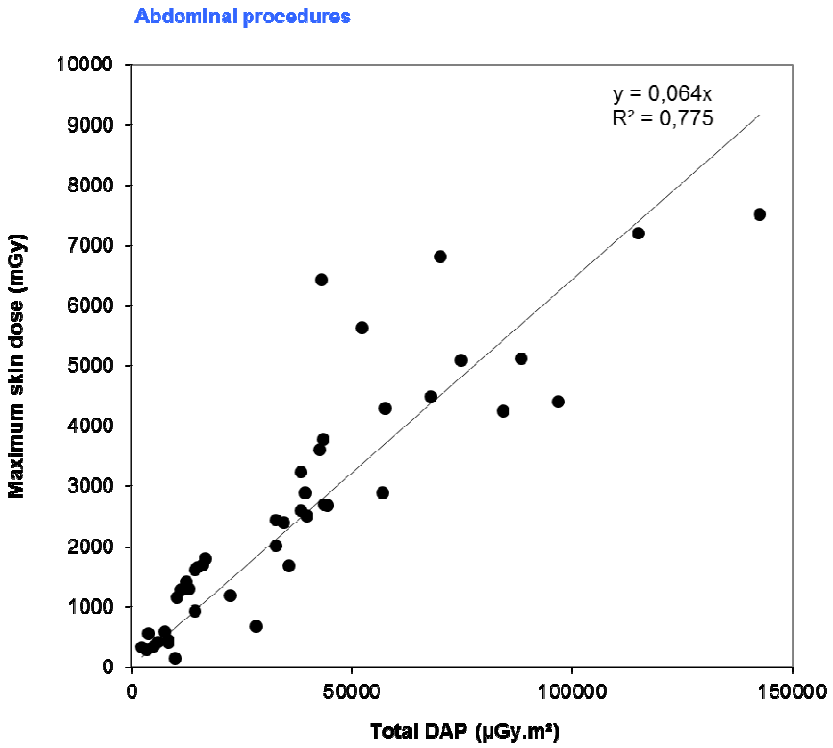


Figure 21: Correlation of the maximum skin dose with the total DAP value for abdominal interventional procedures (TIPS, chemo-embolization of the liver and PTC procedures)

It should be clear that these trigger levels can only be used in practice for X-ray systems with **well calibrated DAP-meters**, with calibration factors in the range of [0.80 – 1.20]. All DAP-meters should be calibrated on annual basis.

Conclusion

In this TRIR project, skin dose measurements are performed for 7 different interventional procedures. The procedures for which a clear risk of deterministic skin damage to the patient exist are the RF ablations, the TIPS procedures, chemo-embolizations of the liver, cerebral embolizations and PTC procedures.
Many factors influence the maximum skin dose of the patient, like complexity of the procedure, equipment used, the choice of procedural parameters like the use of copper filtration, tube voltage and tube current. Extra care should be given to very obese patients. In general, a larger distance between X-ray focus and patient skin should be obtained.

For all procedures, except the AV fistula for heamodialysis, trigger levels are determined in terms of total DAP-value. With this kind of trigger levels available, the interventionalist is able to follow-up the maximum skin dose

of the patient during the procedure and he could be alarmed if the limit for deterministic skin damage is reached. When this happens systematically, an optimization study is advisable on how skin doses can be lowered (extra copper filtration, more tube variation, higher distance between patient and X-ray tube, …). Moreover, the patient can be informed that possible skin damage can occur caused by the procedure.

These trigger levels should not be interpreted as dose limits, but should be regarded as alarm levels for good practice.

It is important that these trigger levels are disseminated to the hospitals to be used in routine practice. The situation in Belgium should evolve in such a way that no patient suffers from skin damage as a consequence of an interventional procedure, unless it is individually justified by the complexity of the procedure and the severity of the pathology.

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Executive summary

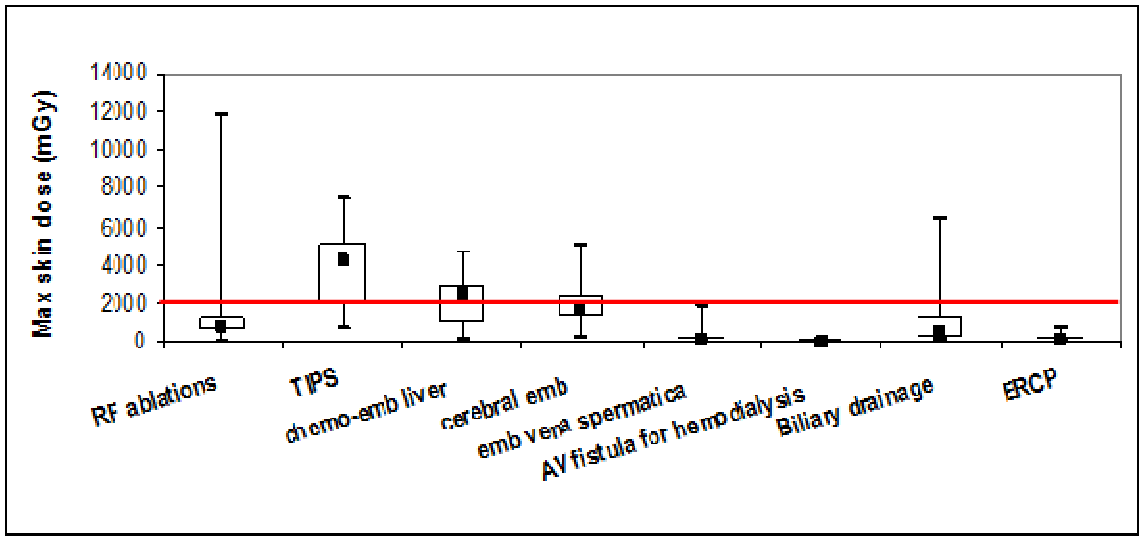
Interventional procedures, by virtue of its low invasiveness, is increasingly used in the treatment of various lesions. Despite being less invasive, the interventional procedure does expose patients to a not negligible dose of radiation, because every stage of the intervention is performed under fluoroscopic guidance. Angiographic acquisition from different projections, now also with 3D reformats, are also mandatory. The Euratom 97/43 directive and the implementation into the Belgian legislation introduced the obligation to carry out dosimetric evaluation for "high-dose practices", including interventional radiology procedures.
In literature, different cases are reported for which patients suffered from deterministic skin damage after a complex interventional procedure under guidance of fluoroscopy. The international Commission on Radiological Protection advises that the entrance skin dose and its location should be recorded when the maximum cumulative dose is expected to be ≥3Gy (≥1Gy in repeated cases).
An important issue is that the interventionalist is not aware of the doses that are given to the skin of the patients during the procedure. Direct measurements of skin doses with thermoluminescent dosemeters (TLDs) or other dosimetric methods have limitations. It is difficult to predict before an examination commences where on the patient's skin the maximum dose will be. Small changes in projection direction can mean a large change in dosemeter reading. This means that a lot of dosemeters are needed to be sure to measure the maxumum skin dose on the patient, which is not possible in routine practice. A trigger level in terms of dose-area-product (DAP) or cumulative dose index (CDI) is much more practical. Both DAP and CDI are measured during the procedure and visible on the monitors of the X-ray system. However, it should be noted that the correlation between the total DAP-value or CDI-value of a procedure and the maximum skin dose somewhere on the patient is not trivial and depends on the type of procedure.

The goal of the TRIR project was to determine which interventional procedures have a potential to deliver skin doses higher than the threshold for deterministic effects (2 Gy). Moreover, we investigated if a correlation could be observed between maximum skin dose and the total DAP or CDI value. If such a correlation could be found, a trigger level was determined. When such trigger levels are available, the interventionalist will be able to follow-up the maximum skin dose to the patient during the procedure and he can be alarmed when the limit for deterministic skin damage is reached.

Following procedures were selected: radiofrequency ablations, Transjugular Intrahepatic Portosystemic Shunt (TIPS), Chemo-embolizations of the liver, Cerebral embolizations, Embolizations of the vena spermatica, Creation or treatment of AV fistula for hemodialysis,

Endoscopic retrograde cholangiopancreaticography (ERCP) and Biliary drainages. As for coronary angiography (CA) and percutaneous transluminal coronary angioplasty (PTCA) procedures skin dose trigger levels were already established in a previous national multicentre study, they are not again included in this study.
For each procedure, accurate skin dose measurements are performed with a grid of thermoluminescent dosemeters attached on the irradiated part of the patient. At the end of the procedure, the total DAP-value and if available also the CDI value was recorded.

Large variations in patient doses are observed between hospitals for the same procedure, but also between patients within the same hospital. In the figure below, an overview is given of maximum skin doses measured for the different procedures.



The procedures with the highest risk to exceed the deterministic skin dose threshold are the TIPS procedures, chemo-embolizations of the liver and the cerebral embolizations. The risks are lower, but still present for RF ablations and biliary drainages (mainly PTC procedures). No skin doses higher than 2 Gy are measured for the embolizations of the vena spermatica, the creation of the AV fistula for hemodialysis and ERCP procedures.

A significant correlation between maximum skin dose and total DAP-value was found for most procedures. In the table below, an overview is given of the determined trigger levels. For completeness, the results of the CA & PTCA procedures are also included from the previous national multicentre study.

		Trigger level (µGy.m²)	Confidence interval (95%)
TIPS & chemo emb. liver		33000	[30000 - 36000]
Cerebral embolizations	Mono-plane	17500	[15000 – 21000]
	biplane	24000	[21500 – 27000]
RF ablations		18000	[16000 – 20000]
Biliary drainages	conventional	16000	[14000 – 17500]
	PTC	18000	[16000 – 21000]
Emb. vena spermatica		27000	[22000 – 35000]
ERCP		29500	[27000 – 33000]
CA & PTCA		12500	/

In view of dose optimization strategies, patient dose should be evaluated for every patient separately for high-risk procedures. For interventional procedures, the main concern is patient skin dose.
As this dose cannot be measured directly in routine practice, the use of the DAP-value is recommended.
This value should be registered in the patient file and compared to the appropriate trigger level for every patient.

If for one specific patient the trigger value is exceeded, the patient can be informed on possible skin burns and followed up more closely.
If DAP-values exceed the trigger level on a regular basis, it should be considered to evaluate the procedure method or the equipment used and perform some radiation protection measures in general.

At this moment it is not recommended to use the CDI-value as trigger level. First of all, at this stage not all used X-ray equipment display this value. Secondly, it is not clear to the project members how this value is determined and it could be different from one manufacturer to the other. And finally, it should also be very clear that CDI is not always an exact calculation of the maximum skin dose. It could be observed that CDI in some cases over-estimates and in other cases under-estimates the maximum skin dose.

As many of the selected procedures for this project are concentrated on the abdominal region, we also investigated if 1 general trigger level could be observed for abdominal procedures performed by the interventional radiologist. Following procedures are included: TIPS, chemo-embolization of the liver and PTC procedures. **A trigger level of 31000 µGy.m²** was determined with 95% confidence interval [28500 – 34500] µGy.m².
However, we should note that the use of such a general trigger level, is not as accurate as using a procedure specific trigger level.

Last but not least, it should be clear that these trigger levels can only be used in practice for X-ray systems with **well calibrated DAP-meters**, with calibration factors in the range of [0.80 – 1.20]. All DAP-meters should be calibrated on annual basis.