EXTREMITY DOSES TO INTERVENTIONAL RADIOLOGISTS

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1. INTRODUCTION

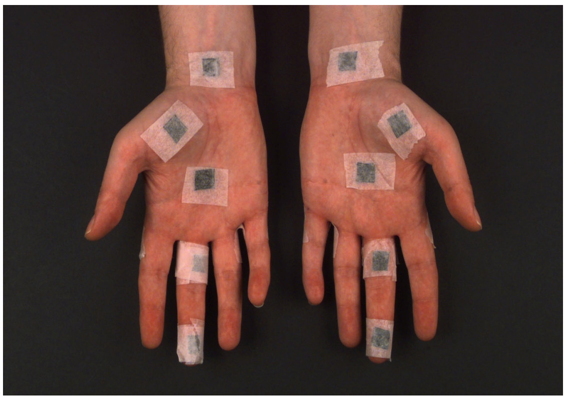
Radiologists performing interventional procedures are often required to stand close to the patient's side when carrying out manipulations under fluoroscopic control. This can result in their extremities receiving a high radiation dose, due to scattered radiation. These doses are sometimes high enough to warrant that the radiologist in question be designated a classified radiation worker. Classification in the UK is a result of any worker receiving or likely to receive in the course of their duties in excess of 3/10ths of any annual dose limit (500mSv to extremities, skin). The doses to the legs of radiologists have received less attention than those to the hands, however the doses may be high, due to the proximity of the legs and feet to scattered radiation. The legs can be exposed to a relatively high level of scattered radiation as the radiation is produced from scatter of the unattenuated beam from the bottom of the patient couch.

The routine monitoring of extremity doses in interventional radiology is difficult due to several factors. Firstly a wide range of interventional procedures is undertaken in every radiology department, and these procedures require many different techniques, equipment and skills. This means that the position the radiologist adopts in relation to scattering medium and therefore their exposure, depends heavily on the type of procedure. As the hands which manipulate the catheters within the patient are often located close to the patients side and to the area under irradiation, the distribution of dose across the hands can be variable, with very high localised doses, making routine monitoring difficult.

The purpose of this study was to determine the magnitude and distribution of dose to the hands and legs of interventional radiologists carrying out a wide range of both diagnostic and therapeutic interventional procedures. To ascertain the most effective method of monitoring the highest dose in accordance with the Basic safety standards directive 96/29/Euratom[3] [1], and to evaluate the effectiveness of any shielding methods available in reducing these doses.

2. METHODS

The doses to the hands and lower limbs were measured using thermoluminescent dosimeters. A total of 16 Li F: Mg,Ti TLD100 chips were attached to both aspects of the hands (figure 1).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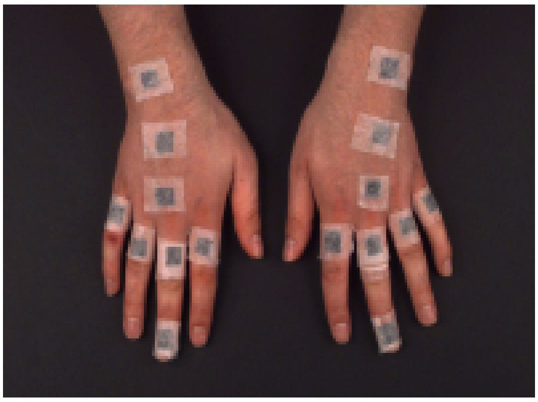
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Figure 1: The location of TLD100 chips on the a) Palmer aspect b) Dorsum aspect of the hands of radiologists per procedure.

TLDs were positioned longitudinally and transversely across the hand in order to obtain information about the distribution of dose across the hands. All TLDs were sealed in plastic and taped to the hands prior to radiologists scrubbing up, these were then worn underneath the surgical glove. Four TLD100 chips were also attached to the theatre trousers of the radiologists per procedure, positioned 80mm below the apex of the patella and on the upper aspect of the foot for both legs. The TLDs were then removed after each procedure or session of procedures and read out using a Harshaw 5500 TLD reader, with background readings being deducted before the calculation of dose. The TLDs were calibrated against air kerma in air, using a Keithley Triad dosimetry system with a 12cc chamber and a Radcal 9010 electrometer with a 6cc chamber, both systems were traceable to a national standard. The TLDs were irradiated free in air using a Seimens Polydoros 80s at x-ray energies from 60 to 90 kVp. The calibration factor and a conversion coefficient [2] was then applied to derive the shallow soft tissue dose (Hp 0.07). Radiologists were monitored in a total of 100 procedures in six hospitals, throughout central and southern Scotland, ranging from large teaching hospitals to smaller district general hospitals. This provided a wide range of procedures, carried out on a wide range of equipment and performed by radiologists of differing experience (table 1).

HOSPITAL	INTERVENTIONAL SIUTE	PROTECTION USED	PROCEDURES	
A	PHILIPS INTEGRIS V300	NONE	BILIARY (6), TIPS (11), STENTS (8), EMBOLISATIONS (11), ANGIOPLASTIES (6), OTHER (17)	
B	SIEMENS MULTISTAR	INTEGRAL Pb SHIELD	STENTS (2), ANGIOPLASTIES (6), OTHER (8)	
C	PHILIPS MULTI-DIAGNOST 3	MOBILE Pb SCREEN	BILIARY (1), EMBOLISATION (1), OTHER (7)	
D	PHILIPS INTEGRIS V3000	NONE	BILIARY (1), OTHER (2)	
E	IGE ADVANTX	INTEGRAL Pb SHIELD	BILIARY (3), TIPS (4)	
F	SIEMENS POLYSTAR	MOBILE Pb SHIELD	STENTS (3), ANGIOPLASTIES (1), OTHER (2)	
			TOTAL	**100**

Table 1: The type of procedures undertaken, the equipment used and lead protection available in the hospitals under monitoring.

In addition, parameters that effect the level of exposure were also noted, such as

- Technique employed; covering parameters such as, the image intensifier (II) size used, magnification, common views used (i.e. oblique and lateral views) and level of collimation.
- Operating settings for specific equipment in use; including operating kV and mAs.
- Number of radiographic exposures
- Screening time
- Presence/absence of shielding and / or tube filtration

This data was then used in the interpretation of TLD results. The DAP reading was also noted and related to the leg exposure.

3. RESULTS

3.1 Magnitude of Hand Doses

The hand that was nearest the x-ray field received 30-40% more dose than that to the other hand, this was generally the left hand. The dominant factor in this was generally the layout of the interventional room, for example where the radiologist could stand in relation to the patient. This was effected by the position and movements of the C-arm, the patients couch and monitoring screens, and also the available space within the room. A wide range of dose was measured across the hands covering many different types of procedures. This reflected the diverse range of interventional procedures available (Table 2).

Procedure	Mean Dose (mSv)
Biliary	0.38 - 5.37
Transjugular intrahepatic porto-systemic shunt (TIPS)	0.04 - 2.05
Angioplasty	0.04 - 1.60
Stent	0.05 - 1.04
Embolisation	0.04 - 0.40
Angiogram	0.02 - 0.06

Table 2: Mean dose (mSv) to the hand nearest the II per procedure over all hospitals studied

Biliary procedures exposed the radiologists to the greatest dose ranging from a mean dose across the hand of 0.38 mSv to as much as 5.37 mSv per procedure. This was expected as the radiologists hands are required to be extremely close to the entry site and to the x-ray field, in order to manipulate the needle/catheter effectively in gaining access to the biliary tree. TIPS procedures resulted in the next highest exposure to the radiologist, with a range of mean doses of 0.04 - 2.05 mSv per procedure. Although the hands are not located near the x-ray field (catheter inserted through the internal jugular vein in neck) the hands are still exposed to a significant dose, this is because the procedure is technically demanding and can take a long period of time with lengthy periods of screening and several radiographic images. Angioplasties and stenting procedures account for 0.04 - 1.60 mSv and 0.05 - 1.04 mSv per procedure respectively. The hands in these cases are positioned further away than during biliary procedures however the dose reflects the technical/anatomical difficulties in deploying balloons and stents in the correct location. Embolisation procedures accounted for 0.04 - 0.40 mSv per procedure and angiograms were significantly lower at 0.02 - 0.06 mSv per procedure. This is because such procedures are purely diagnostic, and therefore once access has be gained, the radiologist can retreat behind a lead screen before angiographic runs are commenced.

There is a significant spread of dose to the hands, not only between procedures but also within the same procedure, this is due to several factors. The procedure undertaken is a clear indicator to the magnitude of the dose to the hand, different procedures require the hands to manipulate the catheter/needle differently. However within the same procedure the spread of dose can be attributed to factors such as:

- Differences in fluoroscopic equipment used
- Variation in patient presentation
- Differences in clinical protocol
- Differences in room layout

Differences between the interventional unit used, in each hospital will clearly affect the dose the operator receives. Each unit had differences in the dose rate at the image intensifier, operating kV and mAs and the presence or absence of tube filtration and lead protection. Differences in the presentation of the patient will also affect the dose received by the operator. Some patients were intolerant to certain procedures or techniques, there vasculature may also be convoluted, requiring additional catheters or views, all of which will increase the screening time and therefore operator dose. Differences in clinical protocols between departments also effect the magnitude of the dose received. For example some departments used slightly different radiographic views depending on either departmental protocol or individual preference. The room layout also affected the dose the radiologist received, as this determined where the radiologist could stand in relation to the patient.

3.2 Distribtuion of hand dose

In general the dorsum of the hand received the slightly higher dose than the palmer aspect of the hand. This was the case in both the left and right hands (figure 2). In most cases a dose gradient existed across both palmer and dorsum aspects of the hands, with the wrist receiving the lowest dose rising to the tip of the middle and ring fingers in the longitudinal direction. However, the transverse gradient was steeper with the index finger receiving the lowest dose rising to the little finger (shown as TIPS in figure 2). The highest dose in these cases was the dose to the base of the little finger

TIPS
BILIARY
EMBOLISATION

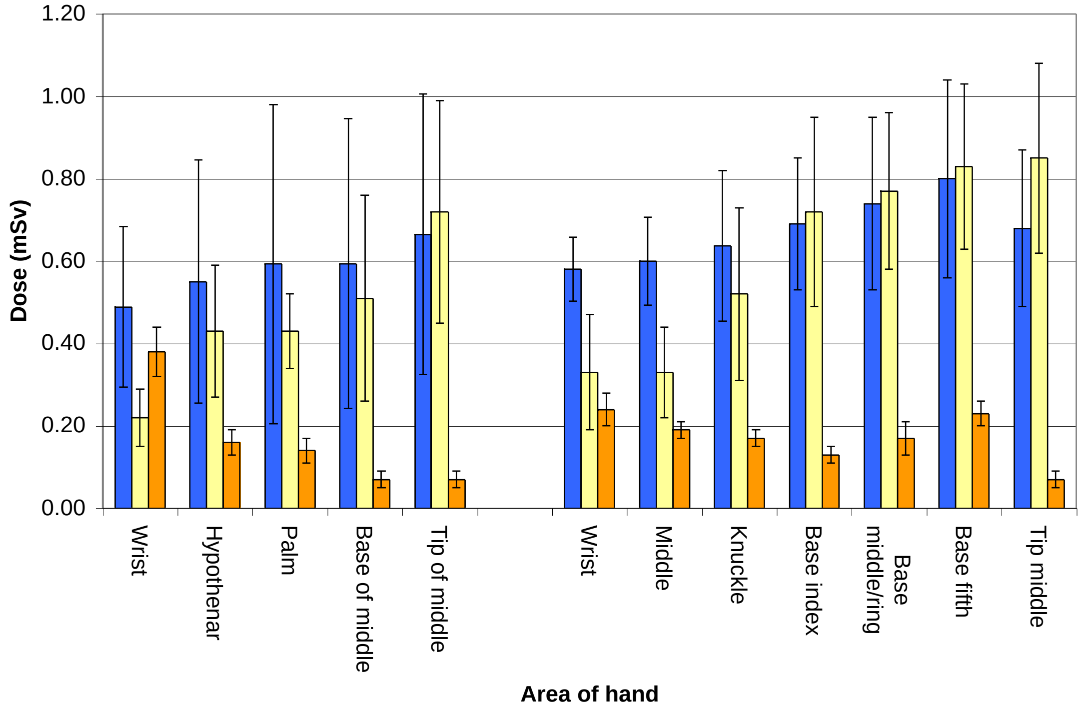

Figure 2: The mean dose across the most exposed hand during TIPS, biliary and embolisation procedures throughout the hospitals monitored.

The exceptions to this rule were biliary and embolisation procedures. Biliary procedures produced an even steeper dose gradient across the hands, this time the tip of the middle and ring fingers in the dorsum of the hand received the highest dose, instead of the little finger. For embolisation procedures this dose gradient was reversed, with the wrist receiving the highest dose, decreasing to the tip of the fingers in the longitudinal direction. In the transverse direction the dose gradient from index to little finger remained. The highest dose on the hand in this case was at the wrist on the palmer side.

3.3 Magnitude of Leg Doses

As with hand dose, the dose to the lower limbs was variable (figure 3). The reason for this is the same as those for the hands. However in this case the magnitude of leg doses was also dependent heavily upon the level and type of lead protection available. In most cases where lead protection was not available the leg dose was similar to or higher than that to the hands. The exception to this rule was biliary procedures, where even if lead protection was not available the dose to the hands was higher. In hospitals A and D where lead protection was not available the mean dose to the lower limbs was 0.40 ± 0.24 mSv, while in hospital C where lead protection was available in the form of a mobile lead skirt this dose was reduced to 0.02 mSv. Lead protection was also available in hospital E, however the dose is higher than that in hospital C. This is due to two factors. Firstly the lead screen formed an integral part of the patient couch, so that it could be raised and lowered with the table. During a biliary procedure the table was raised to a height such that the lead skirt protected the legs adequately but not the feet. The dose to the feet in this case was 0.22 ± 0.02 mSv compared to 0.04 ± 0.03 mSv to the legs. Secondly, during some biliary procedures the lead skirt was also poorly positioned in relation to the radiologist.

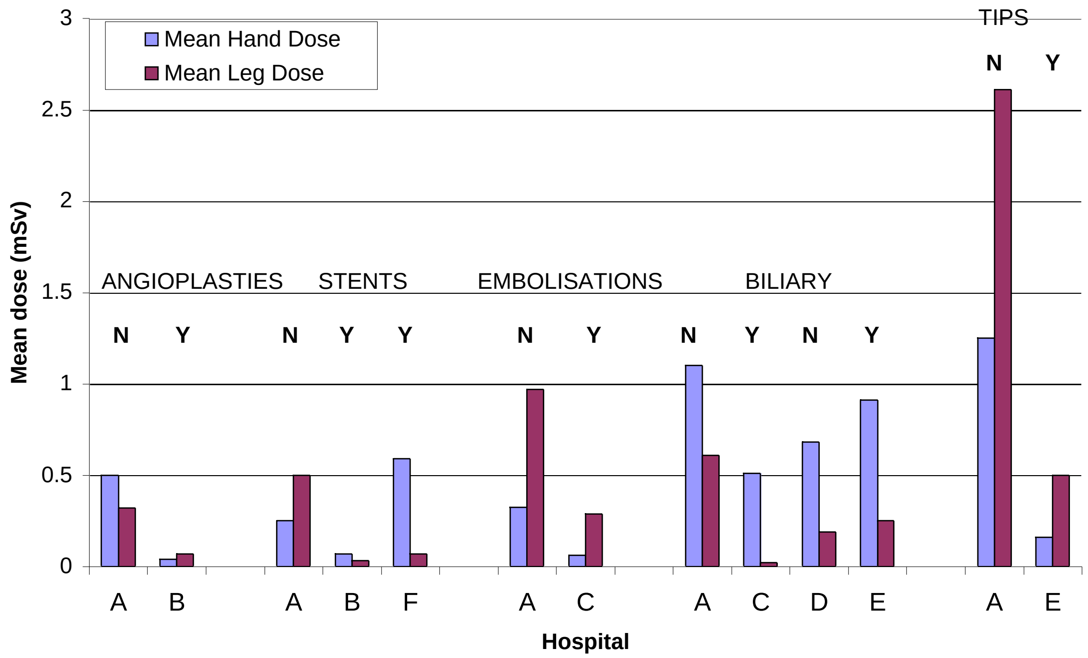

Figure 3: Mean dose (mSv) to the most exposed foot compared to mean dose to the most exposed hand per procedure over all hospitals studied.

During TIPS procedures the leg doses were higher than those to the hand irrespective of whether a lead screen was used or not. In both cases the leg dose was 2- 3 times greater. In hospital A, where no lead protection was available, the mean leg dose was 2.61±0.50 mSv per procedure compared to 1.25±0.53 mSv to the hand. While in hospital E where lead protection was integral to the table the leg dose (0.50±0.40mSv) was still significantly higher than the mean dose to the hands (0.16± 0.10mSv) per procedure. This is because during TIPS procedures the radiologist is required to insert a catheter down the internal jugular vein in the neck, he/she will then remain at the top of the table for the entire procedure manipulating the catheter down towards the liver. Many integral type lead screens however have a very limited range of movement, focussed upon protecting the radiologist standing at the side of the patient. A radiologist standing at the top of the table will have no protection at all from the lead screen positioned at the side.

The dose to the lower limbs during stenting, embolisations and angioplasty procedures ranged from 0.03 - 0.97 mSv per procedure. In hospital A where no lead protection was provided, the leg dose in most cases was higher than that to the hands, indeed in some cases this was approaching 3 times the dose. In hospitals B and F where lead protection was used, the doses were significantly lower. Hospital C had lead screens available, but these were of the mobile type, and were not always put in place prior to commencement of the procedure, the elevated dose here reflects this fact.

3.4 Distribution of leg doses

The leg nearest the x-ray field received on average 34% more dose than that to the other leg, when no lead protection was used. This was generally the left leg (table 3). The average variation in dose across the lower limbs was only 9%. The upper part of the leg nearest the x-ray field generally received a higher dose than that to the foot. While on the other limb, this was reversed with the foot generally receiving the higher dose.

Dose (mSv)	**Procedure**	*Stent*	*Angioplasty*	*Embolisation*	*Biliary*	*TIPS*
Left Limb	Upper leg	0.64±0.20	0.32±0.18	0.94±0.75	0.62±0.38	2.67±0.54
	Foot	0.69±0.17	0.32±0.23	0.77±0.71	0.40±0.24	2.56±0.53
Right Limb	Upper leg	0.50±0.24	0.18±0.08	0.41±0.40	0.40±0.27	1.85±0.48
	Foot	0.48±0.14	0.20±0.09	0.54±0.48	0.41±0.23	1.94±0.53

Table 3: Magnitude and variation in dose (mSv) across the legs during different procedures in all hospitals studied, when no lead protection is used.

3.5 DAP and Leg dose

The relationship between the DAP reading per procedure and the dose to the most exposed limb was also investigated. A strong linear relationship (r = 0.96) was found to exist between the two when no lead protection was used (figure 4). No relationship was found between the screening time and leg dose (r = 0.39).

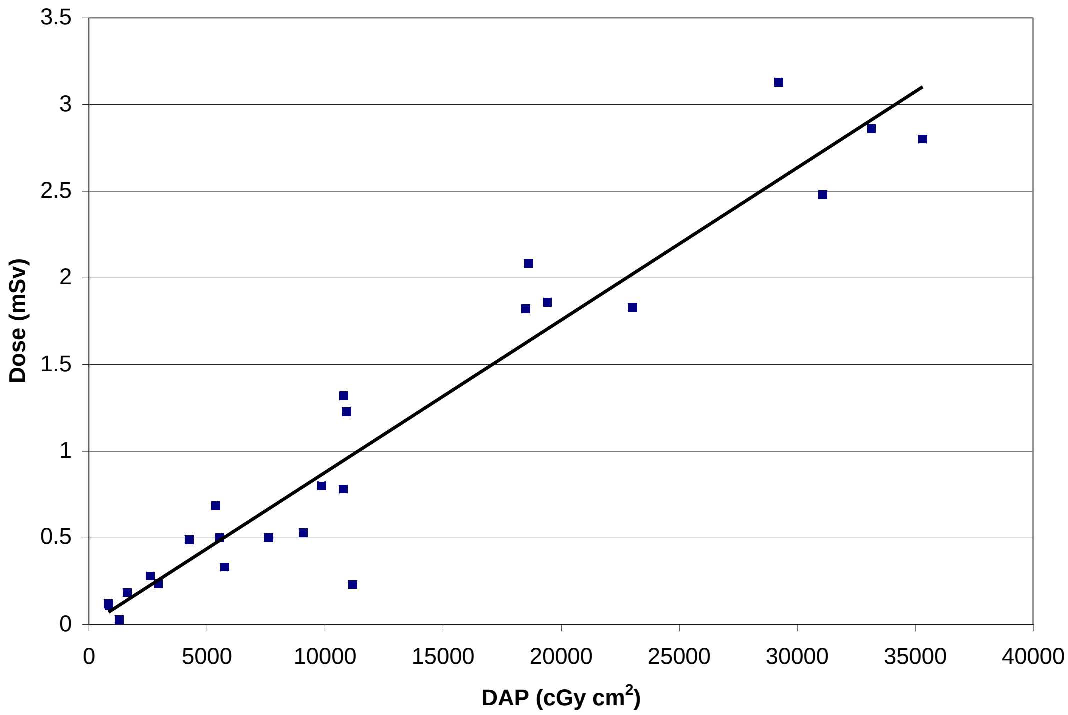

Figure 4: The relationship between the DAP reading and that to the most exposed limb(mSv), without a lead screen

4. DISCUSSION

4.1 Hand doses

The magnitude and distribution of doses that radiologists receive to their hands when undertaking interventional procedures can vary greatly. Of most importance is the type of procedure being performed.

Biliary procedures in general provided the greatest dose to the radiologist, the mean dose across the hands ranged from 0.38 to 5.37 mSv per procedure across all hospitals studied. This was due to the necessity for the radiologist to place their hands very close to the area being irradiated, in order to manipulate the catheter effectively. The closeness of the hands to the entry site is specific to biliary procedures. This resulted in a slightly different distribution of dose across the hand in relation to other procedures. A clear dose gradient existed across both aspects of the hand both transversely and longitudinally, with the tip of the middle and ring fingers on the dorsum of the hand receiving the highest dose.

TIPS procedures provided a wide range of doses to the hands of radiologists, over the two centres studied. Although the hands were not located near the x-ray field the hands still had the potential to receive a significant dose. This was due to the length of some procedures, the technical difficulty in completing the procedure and the differences in equipment used between the two centres. The distribution of the dose was similar to the majority of interventional procedures. The dorsum of the hand again received the highest doses, a dose gradient was again evident over both aspects of the hand, however it was the little finger which routinely received the highest dose. This can be attributed to the positions the fingers adopt when manipulating the catheter. In most interventional procedures vascular access is gained through the seldinger approach. A common site in arterial access is the right femoral artery approach, here after arterial puncture, the catheter can then be advanced to the site to be examined or treated. In most cases during the majority of the procedure the left hand will be closest to the x-ray field as this hand is used to grip the catheter and to advance and/or turn it, while the right hand acts predominantly as a guide. The left hand will therefore routinely be positioned within 15cm of the entry site, while the right hand will be at approximately 50cm from the entry site. This not only means that the left hand will receive the higher dose, but also that the outer border of the left hand receives the highest dose, as this is the area closest to the patient, and therefore in an area of relatively higher scatter. The results from monitoring confirm this. The dose to the hands when performing stenting , angioplasties and angiograms ranged from 0.02 - 1.60mSv per procedure. Stenting and angioplasties were at the higher end of the dose scale, while angiograms contributed the smallest dose, as the majority of the procedure could be performed from behind a lead screen. As with TIPS procedures the technique in manipulating the catheter is very similar and therefore a similar distribution of dose was measured.

Radiologists performing embolisation procedures were exposed to a mean hand dose of 0.04 - 0.40 mSv per procedure. The distribution of that dose was however clearly different from that encountered in the majority of cases such as stenting, angioplasties and angiograms. Here the dose gradient was reversed with the wrist receiving the higher dose, declining towards the tips of the fingers along the length of the hand. The dose across the hand again increased from index to little finger. However the point of highest dose was the wrist on the palmer side.

4.2 Routine monitoring of hand doses

The routine monitoring of interventional radiologists is clearly difficult. A radiologist who's workload consists of a wide selection of both diagnostic and therapeutic procedures would be best served using a TLD ring located at the base of the little finger. In the majority of procedures this is the area of highest dose, and therefore would provide a good indicator of their dose over a period of time. The results suggest that a radiologist wearing a TLD ring on the base of the index or middle fingers would currently be underestimating their dose by approximately 10 - 30%.

Radiologists wearing a TLD ring at the base of the little finger and performing a substantial amount of biliary procedures would underestimate their highest dose by approximately 10%, as it is the tip of the fingers which receive the highest dose in this case. However for those who's workload consists of mainly embolisation procedures this underestimation would be in the region of 20 -50%, and therefore it would be more prudent to monitor such people using a TLD wrist dosimeter.

4.3 Leg doses

The results of this study show that the legs of radiologists may receive a significant radiation dose, which in some cases may be higher than that received by the hands. The magnitude of this dose was dependent mainly upon whether lead protection was used, the procedure and the complexity of that procedure.

During biliary procedures the dose to the legs was always lower than that to the hands (0.2 - 0.61mSv per procedure) irrespective of whether lead protection was used or not. This is because the hands are routinely placed extremely close to the area under irradiation, and therefore receives a higher dose. TIPS procedures exposed the radiologists legs to a mean dose of 0.5 - 2.61 mSv per procedure. The doses measured at Hospital A were the highest measured in the study. The potential for high leg doses during TIPS procedures exist because the procedures are lengthy and can require several different projections of the hepatic region, the legs are also exposed to scattered x-rays of the unattenuated beam from the underside of the couch.

During stenting, angioplasty and angiograms the mean leg dose ranged from 0.03 -0.97 mSv per procedure. In general when lead screens were not used, excluding biliary procedures (hospital A) the dose to the leg approached 2- 3 times that to the hands. If lead protection is used the doses were in most cases significantly reduced, in some cases the dose tended towards the detection limit of the TLDs used. The exceptions to the rule were hospitals C&E and highlight the importance of the correct application and good design of lead screens. Hospital C uses a mobile lead screen, which is mounted on castors and can be located anywhere within the room. This poses a problem, as the screen is required to be put in place before the procedure starts. Consequently this was not used during the majority of embolisation procedures carried out, and therefore the leg doses are significantly higher than those to the hands. Hospital E however have a lead screen which is integral to the patients couch, they however have a limited range of lateral movement, and are therefore unsuitable when undertaking TIPS procedures.

The study shows that the legs can be effectively protected by the use of lead screens. However also highlighted was the importance of choosing a lead screen which is most suitable for the workload within a department. For those centres who carry out a general workload, the integral type of lead screen may be best, as no conscious decision is needed to use it, and therefore it will always be in place to protect the lower limbs. For those who carry out a range of therapeutic procedures such as TIPS, it may be prudent to purchase an additional mobile screen.

4.4 Routine monitoring of leg doses

The routine monitoring of leg doses is problematic. A rule of thumb was established which could be used to establish whether a lead screen should be purchased. A DAP reading of 100 Gy cm^2 will give a dose of approximately 1mSv to the most exposed leg. If lead protection was available this leg dose would drop to 0.02mSv.

5. CONCLUSIONS

Radiologists performing interventional procedures can receive significant doses not only to their hands but also to their legs and feet. These doses can be high enough to warrant classification. Routine monitoring of the hands and legs are difficult. The magnitude and distribution of dose across the hands can vary greatly between procedures. A TLD ring located at the base of the little finger would effectively measure the highest dose on the hand, for those radiologists with a general workload. For those radiologists who undertake a significant number of biliary procedures, the highest dose may be underestimated by approximately 10% by wearing a TLD ring at the base of the little finger. Radiologists who's workloads consists of mainly embolisation procedures, this monitoring position would be inappropriate, as an underestimation of 20 -50% would ensue. Therefore it would be prudent to ensure such radiologists were monitored at the wrist with the dosimeter facing towards the palm.

The study has shown that the dose the legs receive when carrying out interventional procedures could be significant. For those units that had no lead protection available, the doses were as much as 2-3 times that to the hands. A lead screen, whether integral to the table or freely mobile, provides not only a effective barrier against radiation but is also cost effective. Care should be taken however when purchasing a new unit as to the appropriate screen type. A rule of thumb was established to help in the routine monitoring of leg doses, this can be used to ascertain whether a lead screen should be purchased. A DAP reading of 100 Gy cm^2 results in a dose of 1mSv to the most exposed leg.

6. REFERENCES

1. 'Council Directive 96/29 Euratom of 13 May 1996 laying down basic safety standards for the protection of health workers and the general public against the dangers arising from ionising radiation'. *Official Journal of the European Communities* 1996 **39** (L159) 1-114
2. The International Commission on Radiological Protection (74). Conversion coefficients for use in radiological protection against external radiation. Pergamon, Oxford, 1997.

7. ACKNOWLEDGEMENTS

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