Report on the analysis of the measurement and simulation results, with an evaluation of the doses and radiation protection measures

Work Package 1, ORAMED

December 2010

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1 Introduction

One of the main objectives of the ORAMED project was to optimize the working procedures in the medical field with respect to radiation protection, giving special emphasis on improving the knowledge on extremity and eye lens exposures.

The first Work Package (WP1) of the project is dedicated to the extremity and eye lens doses in interventional radiology and cardiology (IR/IC). The very first outcome of WP1 was the establishment of protocols that were used in the measurement and simulation campaigns (1). Immediately after the protocols, the procedures that should be monitored and the parameters that need to be examined were identified. For more than two years, measurements and simulations were performed by the ORAMED WP1 partners. The results of these campaigns were presented in the second deliverable (2).

In the present final report the results of the measurements and simulations are analysed and compared in detail. The report contains a systematic evaluation of the effect of the different radiation protection measures on the occupational doses. The data from the measurements and simulations are compared. Moreover, extrapolation to annual doses has been done to show whether and when the annual limits are exceeded.

2 Measurements

A first analysis of the measurements has been performed using simple statistics. The dose equivalent to the skin (at 0.07 mm depth), $H_p(0.07)$, has been used for the measurements, which is the operational quantity used to monitor the equivalent dose to the skin. In the present project the same quantity has been used for the measurement of the doses received by the lens of the eyes. The measurement results are presented in box plots (presenting minima and maxima, the 1st and 3rd quartile and median and average values). In most of the cases the ratios of $H_p(0.07)$/KAP (Kerma Area Product) were used. The factors that are examined for their influence on the measured doses in the various positions (eyes, fingers, wrists and legs) are: the access of the catheter (position of the physician), the tube configuration, the use of table and ceiling suspended shield (shown in figure 1), the experience and whether the operator stays inside or goes outside the room during the image acquisitions. For each of these factors a quantitative value of their influence on the doses has been calculated. Next to the box plot analysis, it was decided to use a multi variant analysis since a lot of these factors could interact with each other. The two-way analysis of variance (ANOVA) tests (also called two-factor analysis of variance) that measure the effects of two factors simultaneously were used for the study of the parameters that affect the results. The significance levels that were used for testing the null hypotheses were 0.05. The statistical packages used for this purpose were the SPSS and STATISTICA. Moreover, the position where the maximum dose was obtained has been examined for each procedure. The annual limit of each position (150 mSv for the eyes, and 500 mSv for the extremities) has also been used to show the significance of the recorded maximum doses. Finally correlations between the various dosimetric positions and the KAP values have been attempted for procedures with similar working conditions. Linear relationship was checked between the variables examined. Values of

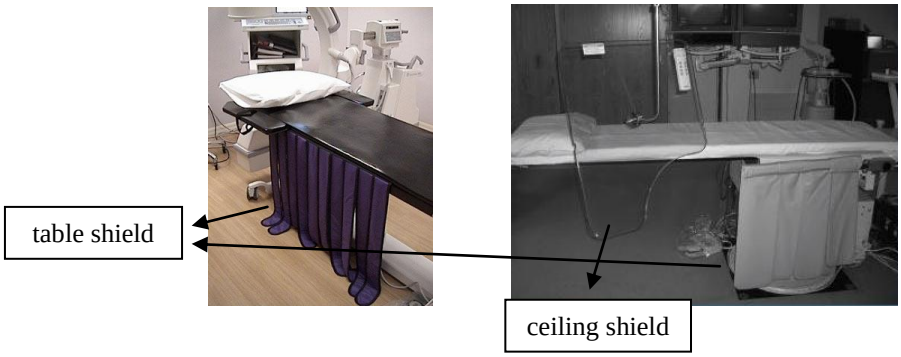


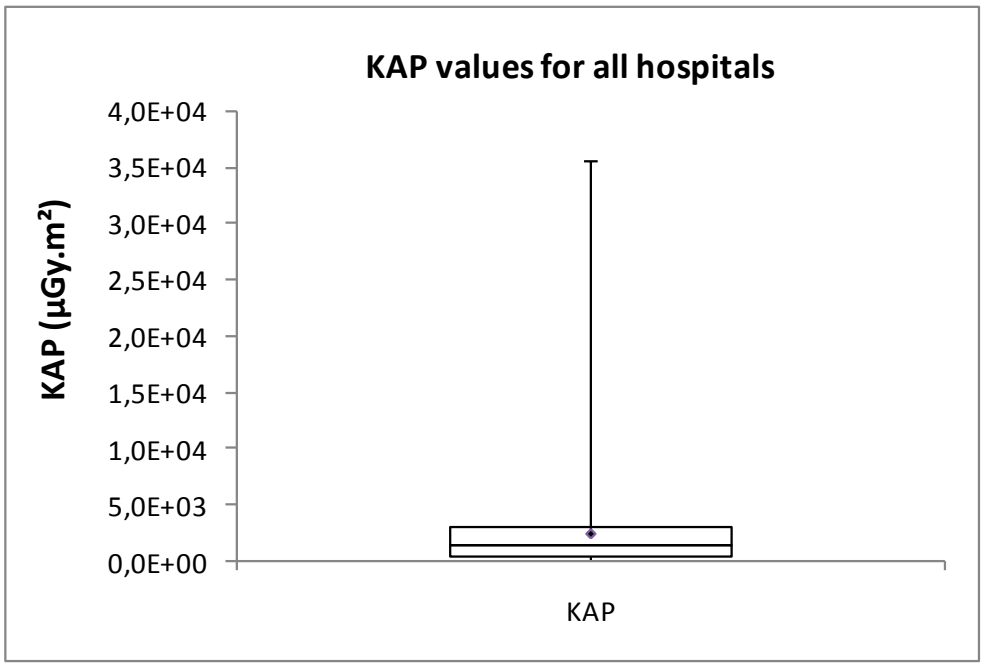
Figure 1: Room protective equipment used in the rooms

the Pearson coefficient higher than 0.7 were considered important. The results from each procedure separately, are presented further on this document.

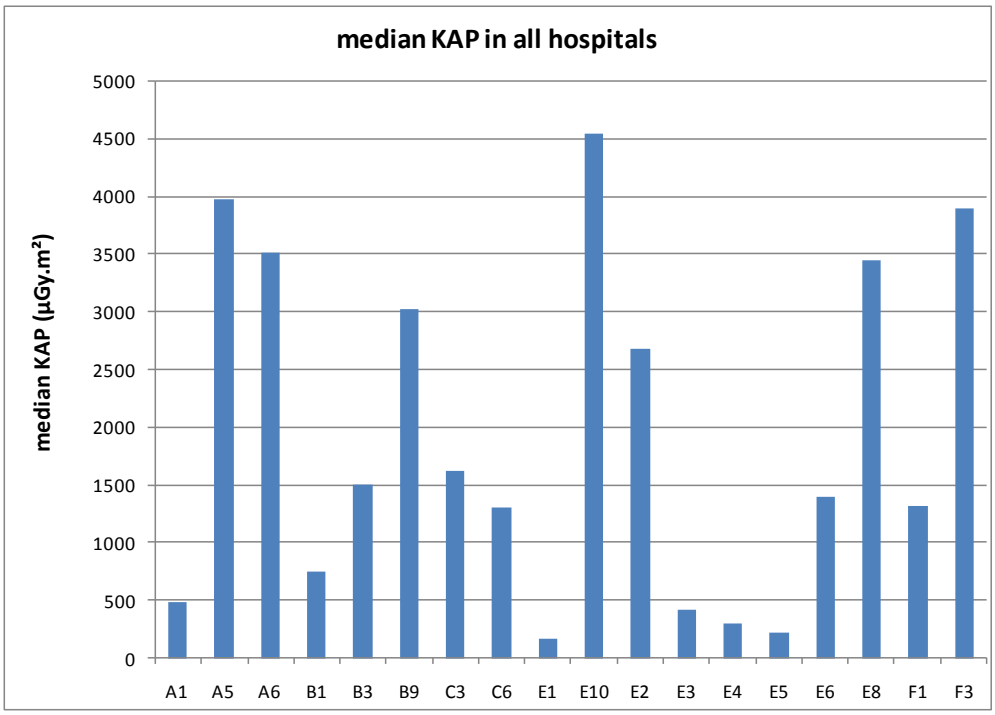
2.1 Endoscopic Retrograde CholangioPancreatographies (ERCP)

2.1.1 General information

In total 168 procedures were monitored in 18 hospitals. The following graph presents a box plot from the KAP values monitored for this procedure in all hospitals and the next one, the median KAP values for each hospital. It can be noticed that a large variation exists in the amount of radiation used to perform these procedures.



Graph 1: Box plot of the KAP values for the ERCP procedures



Graph 2: Median KAP values at the various hospitals where the measurement campaign for the ERCP procedures took place

In the next graphs some statistics are presented giving information on the use of the room protective equipment, personal protective equipment, tube configuration and the frequency of the operator's practice staying inside or going outside the room during the image acquisitions.

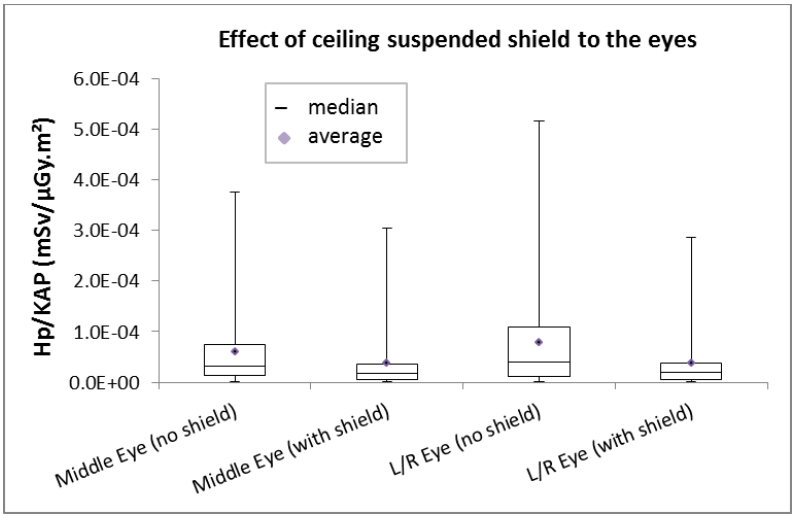
Graph 3: Statistics concerning the use of the room protective equipment, personal protective equipment, tube configuration and staying inside or going outside of the room during the image acquisitions

As it is shown from the graphs in all of the cases some kind of personal protective equipment has been used. However, for 33% of the cases where no room protective equipment has been used (table or ceiling suspended shield). Finally, almost half of the cases that were monitored are performed with the tube being above the operating table.

The H_p/KAP values at the various dosimetric positions measured for the ERCP procedures in each hospital are presented in Appendix 1.

2.1.2 Effect of room protective equipment and tube configuration

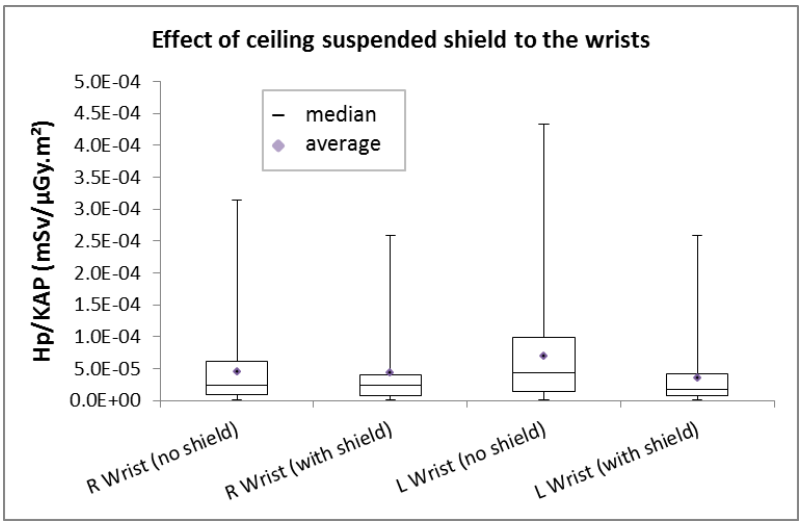
The use of ceiling suspended shield was examined for the effect on the reduction on the eye, finger and wrist doses. The results are presented in the following graphs. The reduction ratio is also calculated by using the median values.



with ceiling:	59 cases
without ceiling:	110 cases

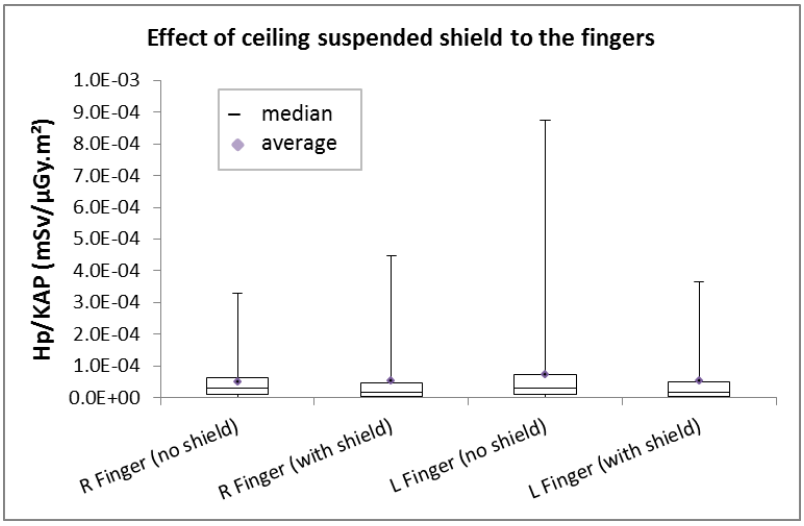
% reduction		
M eye	L eye	
40	54	median
ratio (without/with)		
1.66	2.20	median

Graph 4: The effect of the ceiling suspended shield to the eye doses



% reduction		
R wrist	L wrist	
1	60	median
ratio (without/with)		
1.01	2.49	median

Graph 5: The effect of the ceiling suspended shield to the wrist doses



% reduction		
R finger	L finger	
45	46	median
ratio (without/with)		
1.82	1.85	median

Graph 6: The effect of the ceiling suspended shield to the finger doses

From the above graphs, it is seen that there is an important reduction on the eye, wrist and finger doses. The reduction ratio ranges from 1.01 (no effect on right finger) to 2.5 times (for the left finger).

When the tube configuration is also taken into account the reduction of the doses is examined separately for each case: tube above and shield is absent, tube above and shield is present, tube below and shield is absent, tube below and shield is present. The above graphs are re plotted and are presented for the eyes, wrists and fingers.

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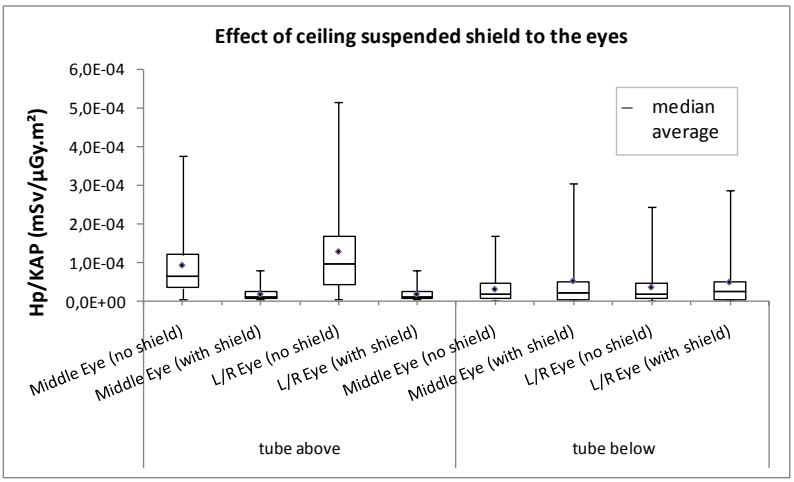
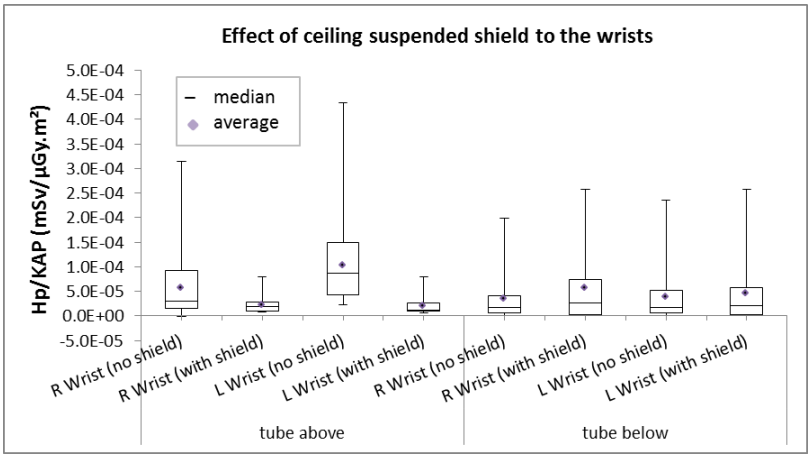


tube above	with ceiling:	27 cases
	without ceiling:	49 cases
tube below	with ceiling:	32 cases
	without ceiling:	61 cases

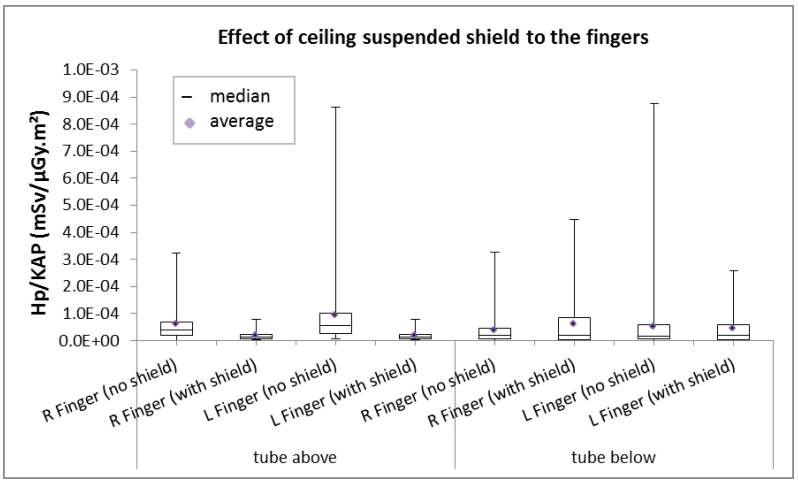
% reduction			
Tube above		Tube below	
M eye	L eye	M eye	L eye
81	88	-24	-44
ratio (without/with)			
5	8	0.80	0.69

Graph 7: The effect of the ceiling suspended shield to the eye doses when tube configuration is taken into account



% reduction			
Tube above		Tube below	
R wrist	L wrist	R wrist	L wrist
38	86	-53	-28
ratio (without/with)			
1.62	7.11	0.65	0.78

Graph 8: The effect of the ceiling suspended shield to the wrists when tube configuration is taken into account

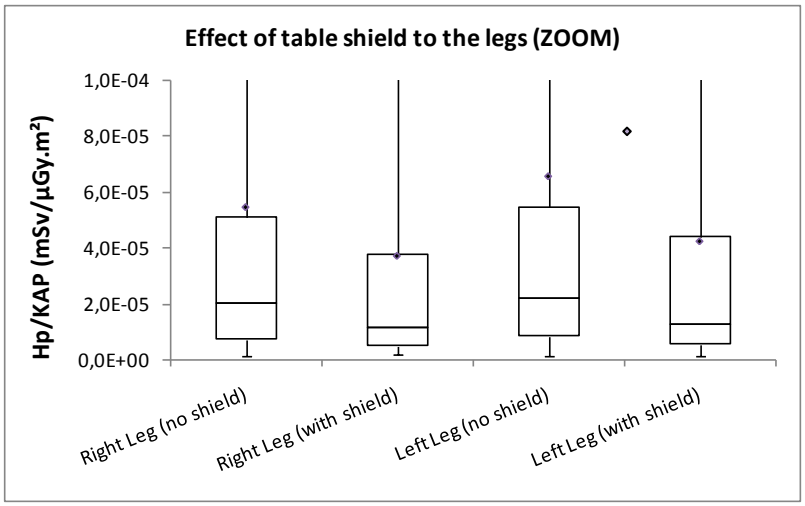


% reduction			
Tube above		Tube below	
R finger	L finger	R finger	L finger
70	79	-17	-27
ratio (without/with)			
3	5	0.85	0.79

Graph 9: The effect of the ceiling suspended shield to the finger doses when tube configuration is taken into account

From the above graphs it is clearly seen that the effect of the ceiling shield is very important for overcouch irradiations, as it can reduce the doses from 1.6 (right wrist) up to 8 times (left eye). The dose reduction is more significant to the eyes for this tube configuration. On the other hand, for undercouch irradiations the ceiling shield does not seem to affect the doses, however there are cases where the doses are high when no ceiling shield is used and the tube is below the operating table, which should not be overlooked.

The use of the table shield was studied for the effect on the leg doses. The results are presented in the following graph. The reduction ratio is also calculated from the median values.



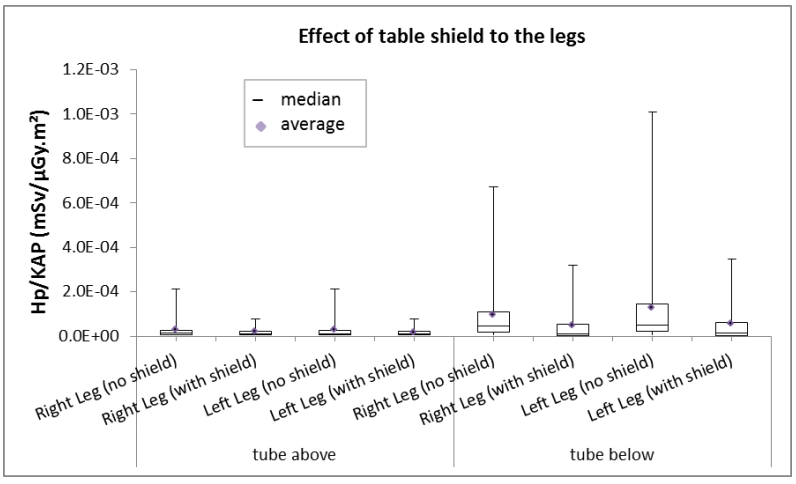
with table:	87 cases
without table:	82 cases

% reduction		
R leg	L leg	
44	44	median
ratio (without/with)		
1.79	1.77	median

Graph 10: The effect of the table shield to the leg doses (ZOOM graph)

From the above graph, it is shown that the use of table shield is important in reducing the leg doses. The average reduction ratio for both legs is 1.78.

When the tube configuration is taken into account the reduction of the doses is examined separately for each case: tube above and shield is absent, tube above and shield is present, tube below and shield is absent, tube below and shield is present. The previous graph is presented in the following.



tube above	with table:	29 cases
	without table:	47 cases
tube below	with table:	57 cases
	without table:	35 cases

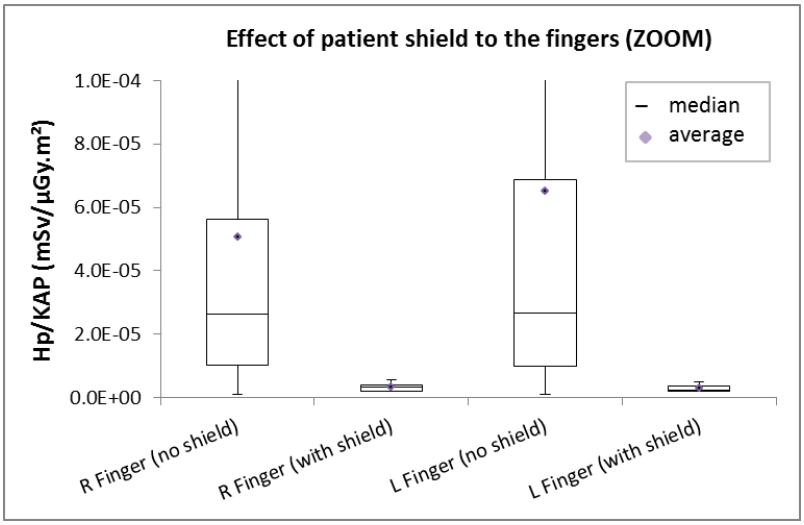
% reduction			
Tube above		Tube below	
R leg	L leg	R leg	L leg
33	12	72	67
ratio (without/with)			
1.48	1.14	3.57	2.99

Graph 11: The effect of the table shield to the leg doses when tube configuration is taken into account

When the table shield is examined in conjunction with the position of the tube configuration it is clear that its effect is more significant for undercouch irradiations. The dose reduction in this case is 3-3.6 times.

There was also a hospital where a lead curtain going all the way from II to the X-ray tube was used (figure 2). The measured doses in this case were all zeros, as it can be seen from the next graph and the accompanied table with the reduction ratios.

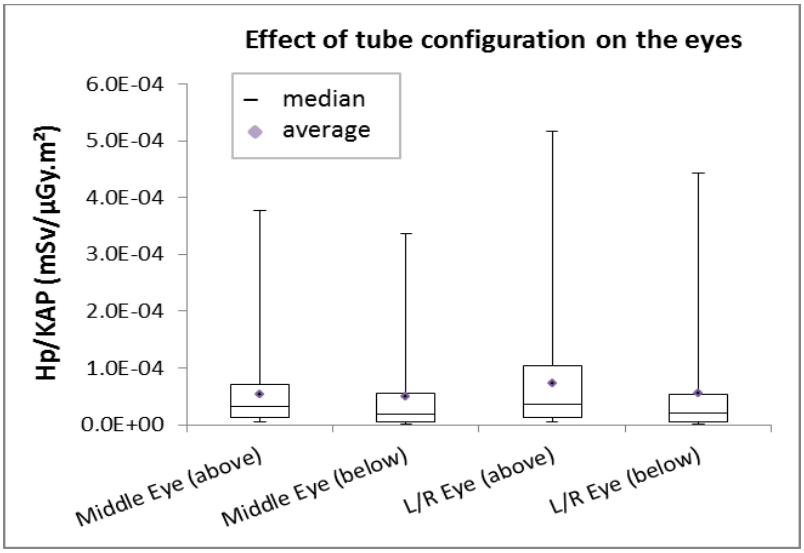
Figure 2: Patient protective equipment used for the ERCP procedures



Graph 12: The effect of the patient shield to the finger doses (ZOOM graph)

% reduction		
R finger	L finger	
88	91	median
ratio (without/with)		
8.21	11.50	median

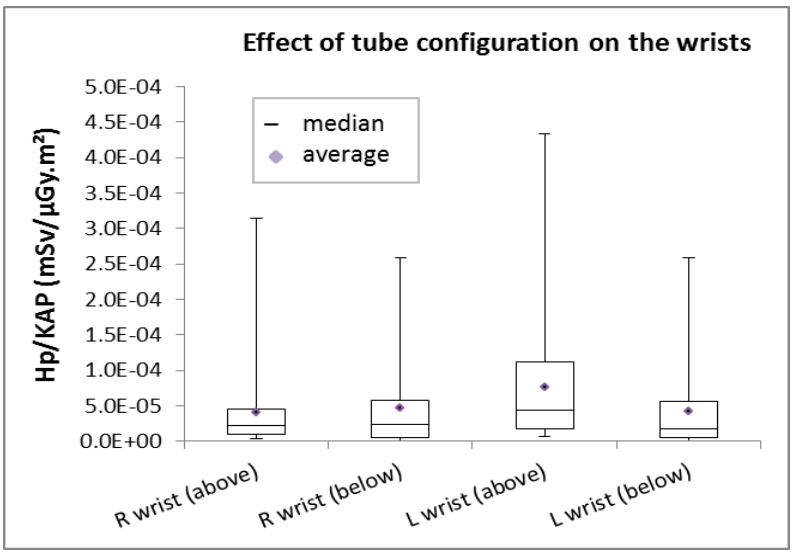
Furthermore, the effect of tube configuration on the eye, wrist, finger and leg doses was studied. The relevant box plots are presented in the following.



Graph 13: The effect of the tube configuration to the eye doses

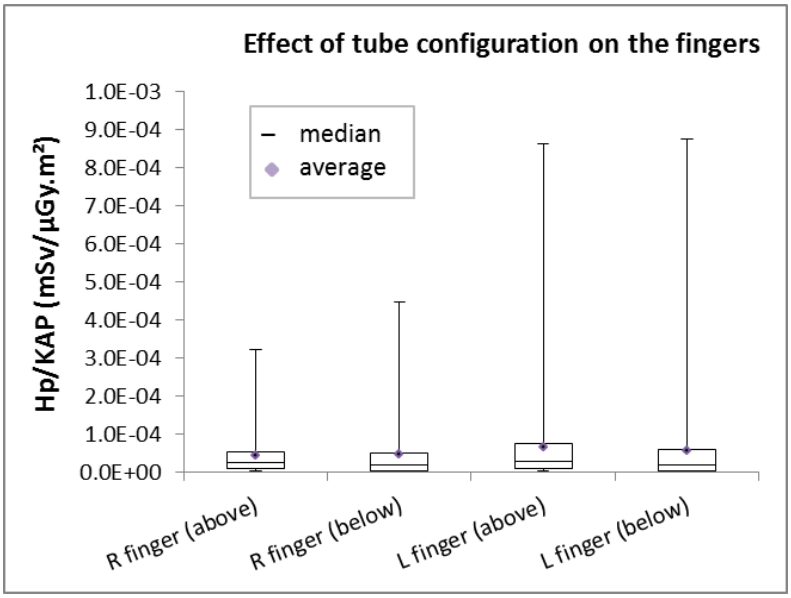
Above:	75 cases
Below:	93 cases

% reduction from below		
M eye	L eye	
41	45	median
ratio (above/below)		
1.70	1.82	median



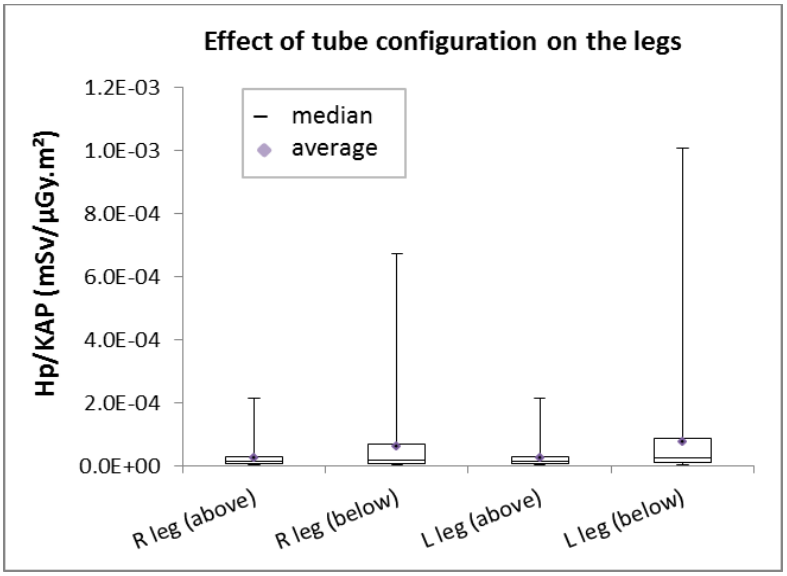
Graph 14: The effect of the tube configuration to the wrist doses

% reduction from below		
R wrist	L wrist	
-5	59	median
ratio (above/below)		
0.95	2.43	median



Graph 15: The effect of the tube configuration to the finger doses

% reduction from below		
R finger	L finger	
27	37	median
ratio (above/below)		
1.37	1.59	median

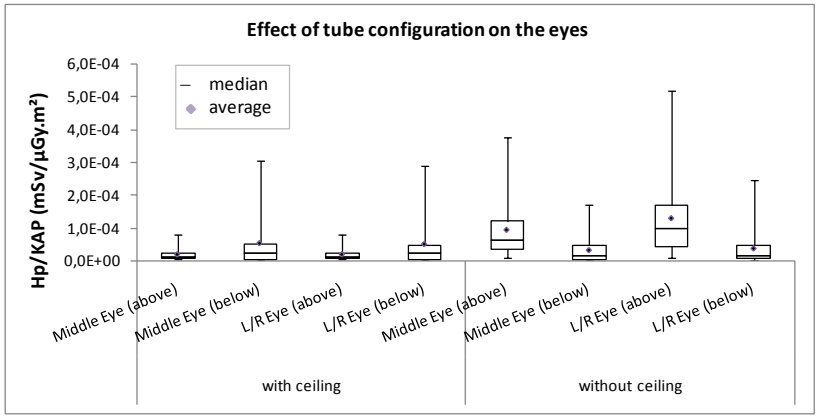


% reduction from above		
R wrist	L wrist	
31	50	median
ratio (below/above)		
1.45	2.01	median

Graph 16: The effect of the tube configuration to the leg doses

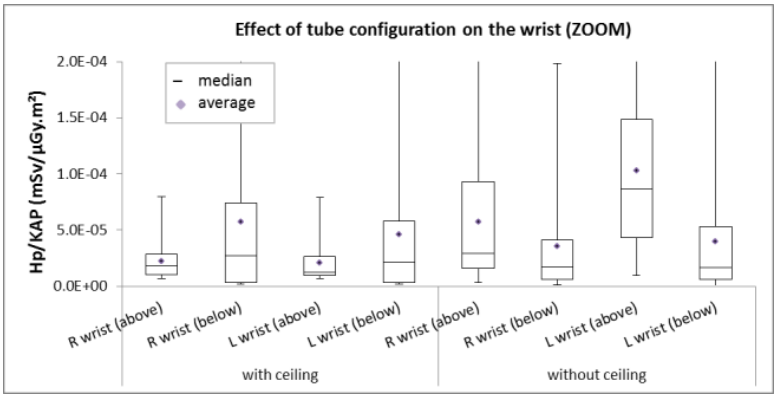
When the tube is positioned below the operating table the doses to the eyes, wrists and fingers are lower than in the case where the tube is above. The reduction ratio (above/below) that is observed ranges from 1 to 2.4. However, as expected, the opposite effect is observed for the legs; the leg doses are higher when the X-ray tube is below the table.

When the ceiling shield is also taken into account the effect of the tube configuration seems not to be so important in cases where ceiling shield is used as shown in the following graphs.



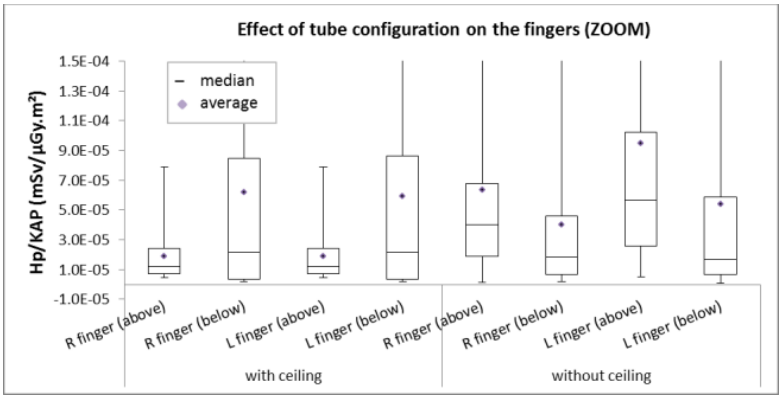
% reduction from below			
with ceiling		without ceiling	
M eye	L/R eye	M eye	L/R eye
-82	-109	72	82
ratio (above/below)			
0.55	0.48	3.60	5.56

Graph 17: The effect of the tube configuration to the eye doses when the ceiling suspended shield is taken into account



% reduction from below			
with ceiling		without ceiling	
R wrist	L wrist	R wrist	L wrist
-47	-75	41	81
ratio (above/below)			
0.68	0.57	1.69	5.19

Graph 18: The effect of the tube configuration to the eye doses when the ceiling suspended shield is taken into account (ZOOM graph)

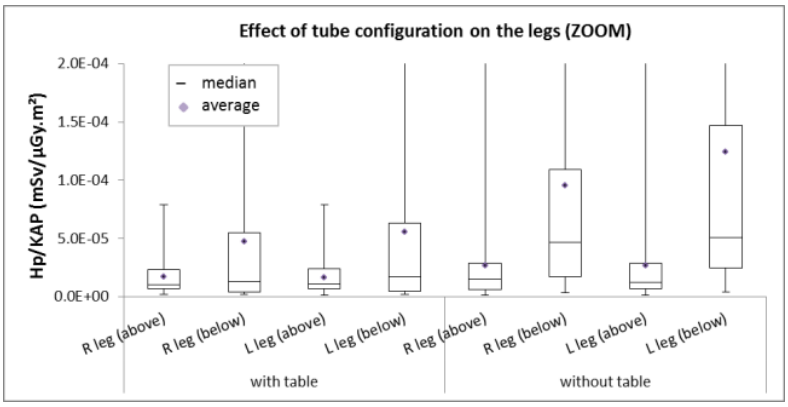


% reduction from below			
with ceiling		without ceiling	
R finger	L finger	R finger	L finger
-77	-77	54	70
ratio (above/below)			
0.56	0.56	2.20	3.35

Graph 19: The effect of the tube configuration to the eye doses when the ceiling suspended shield is taken into account (ZOOM graph)

However, when the ceiling shield is not used the effect of the tube configuration is very important in reducing the doses. The respective reduction ratios range from 1.7 (right wrist) to 5.6 (left eye).

The following graph shows the effect of tube configuration on the leg doses when the table shield is taken into account. The higher reduction is observed when the table shield is not used (3 to 4.1 times for the right and left leg respectively).



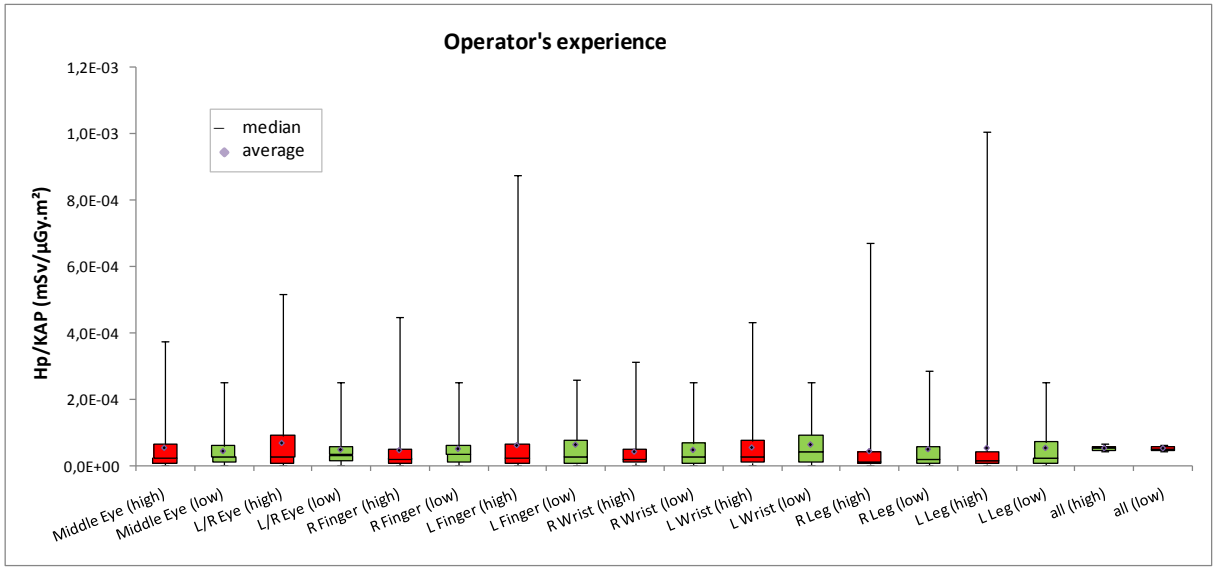
% reduction from above			
with table		without table	
R leg	L leg	R leg	L leg
21	36	67	76
ratio (below/above)			
1.27	1.56	3.04	4.09

Graph 20: The effect of the tube configuration to the eye doses when the ceiling suspended shield is taken into account (ZOOM graph)

2.1.3 Effect of experience

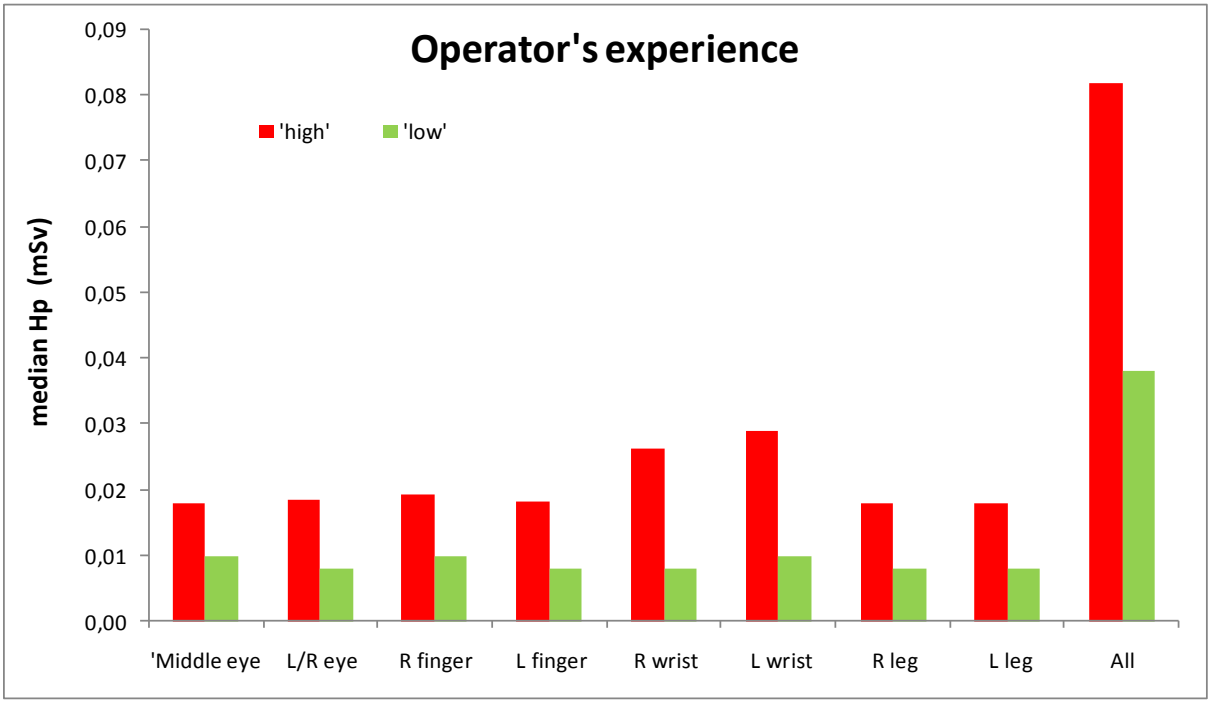
The experience of the operator was considered as one factor that may affect the doses. The following graphs present the doses to the various dosimetric positions for high and low experienced personnel for the H_p and the H_p/KAP values. The normalized values, H_p/KAP, are considered to present the effect of experience independently from the complexity of the procedure. The "all" column presents the median value of all dosimetric positions. It was considered as a good index for the impact of the "experience" parameter.

Graph 21: The effect of the operator's experience on the Hp values (ZOOM graph)



Graph 22: The effect of the operator's experience on the Hp/KAP values.

The median Hp(0.07) values for the various positions are also presented in the following graph.

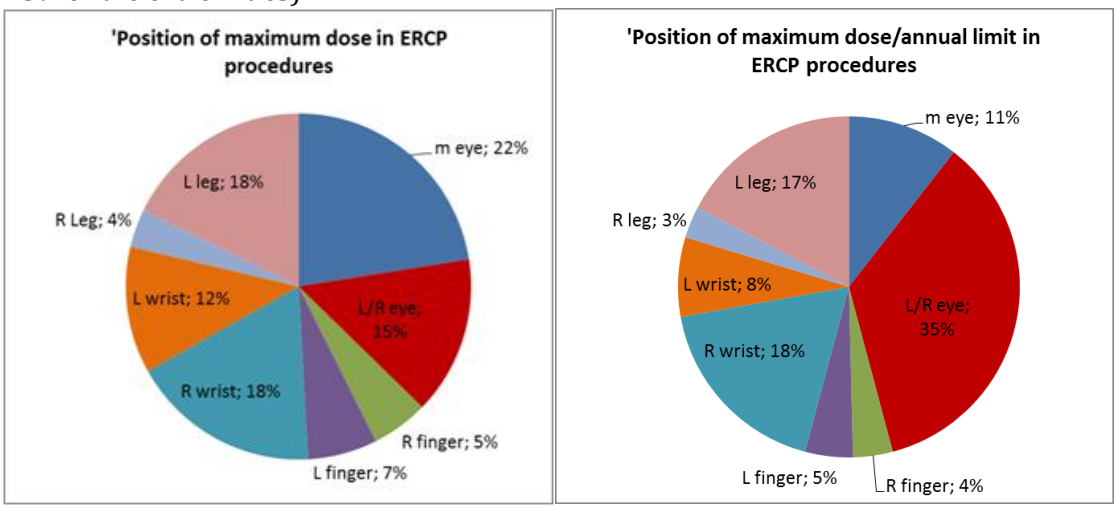


Graph 23: The median $H_p(0.07)$ values for high and low experienced operators.

From the graph with the H_p values, it is shown that higher H_p values are observed for operators with high experience and maybe this is due to the fact that they perform more complex procedures. Moreover, from the graph with the H_p/KAP values, lower H_p/KAP values are observed at fingers, wrists and legs for high experienced operators which strengthens the previous assumption. Finally, for median $H_p(0.07)$ values, all dosimetric positions have higher doses for high experienced personnel.

2.1.4 Position of the maximum

For the position of the maximum two pie charts are presented: one with the frequency of the position where the maximum dose was recorded in the ERCP procedures and the other with the maximum dose recorded divided by the respective annual limits (150 mSv for the eyes and 500 mSv for the extremities).



Graph 24: Position of the maximum dose (on the left) and maximum dose divided by the respective annual limit (on the right)

From the above graph (left part) it is shown that there is a quite large distribution of the position of the maximum dose. Four positions are encountered most often: L/R eye, R wrist, L wrist and L

leg. When weighting the maximum dose by the annual dose limits then a larger contribution comes from the eyes (35% and 11% for the left and median eye respectively).

2.1.5 Maximum doses

A table with the maximum doses measured from one single procedure, along with some irradiation conditions, is presented.

Table 1: The table presents the maximum doses in each dosimetric position and the conditions during which these doses were measured

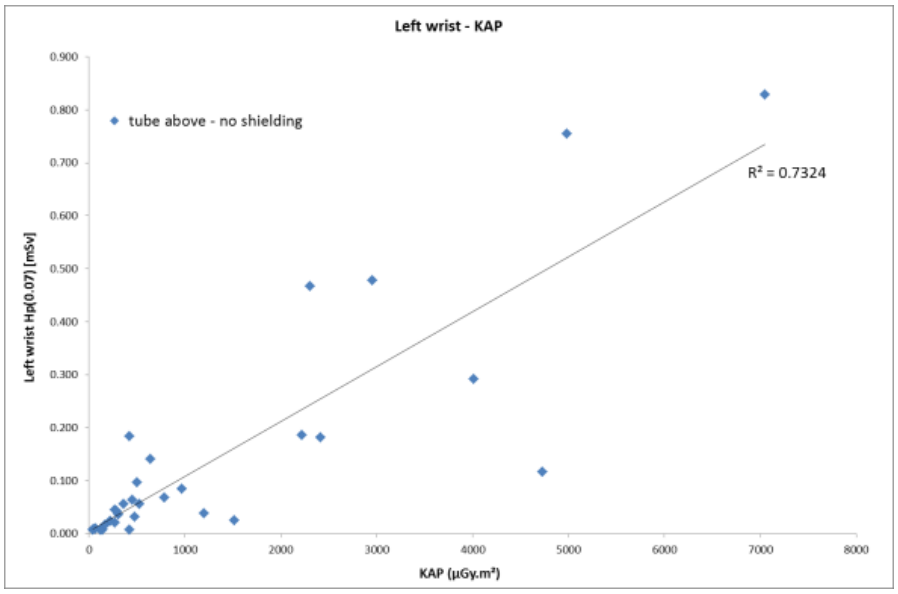
	left eye	middle eye	left finger	right finger	left wrist	right wrist	left leg	right leg
maximum dose [mSv]	4,1	3,2	2,0	0,90	0,80	1,3	3,700	2,8
Tube configuration	above		above	above	above	above	below	
out during image	no		no	no	no	no	no	
room protection	table shield		none	table	none	table	none	
KAP [µGy.m²]	11451		2304	7361	7046	11451	18048	

From the table it is shown that most of the doses are zero though during the ERCP procedures, some high values have been measured. These values are recorded when all unfavorable conditions are cumulated or when KAP values are quite high.

2.1.6 Correlations

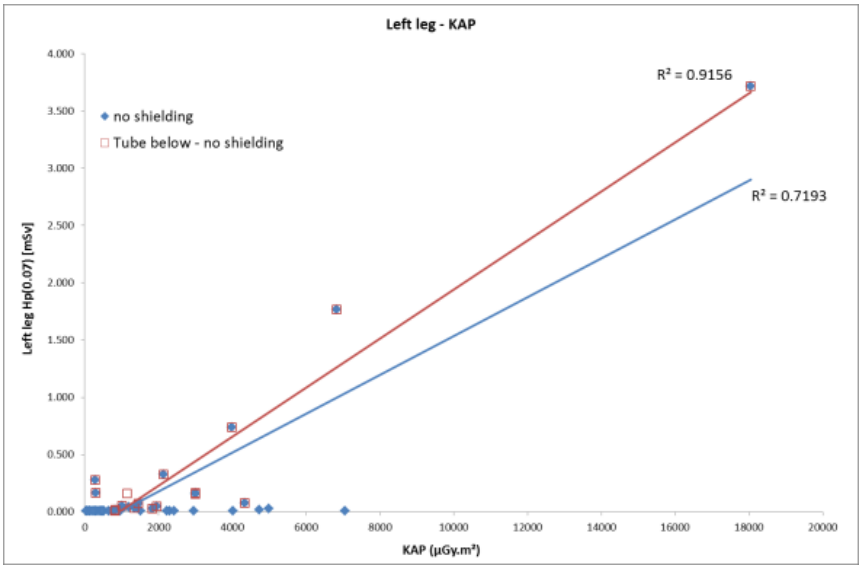
The only correlations that were observed are between some dosimetric positions and the respective KAP values.

- *Left wrist ↔ KAP (tube above and no shield)*



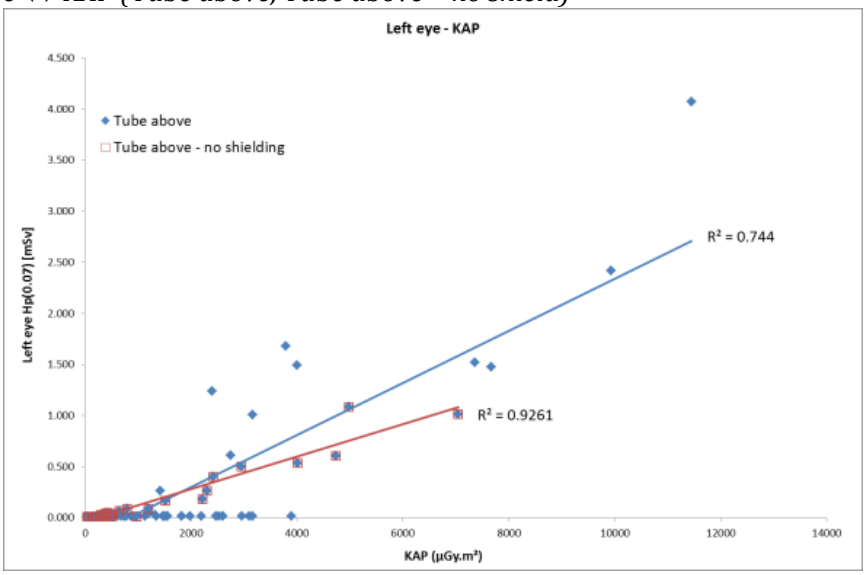
Graph 25: Correlation between the Left wrist and KAP values when the tube is above and there is no shield

- *Left leg ↔ KAP (No shield, Tube below -no shield)*



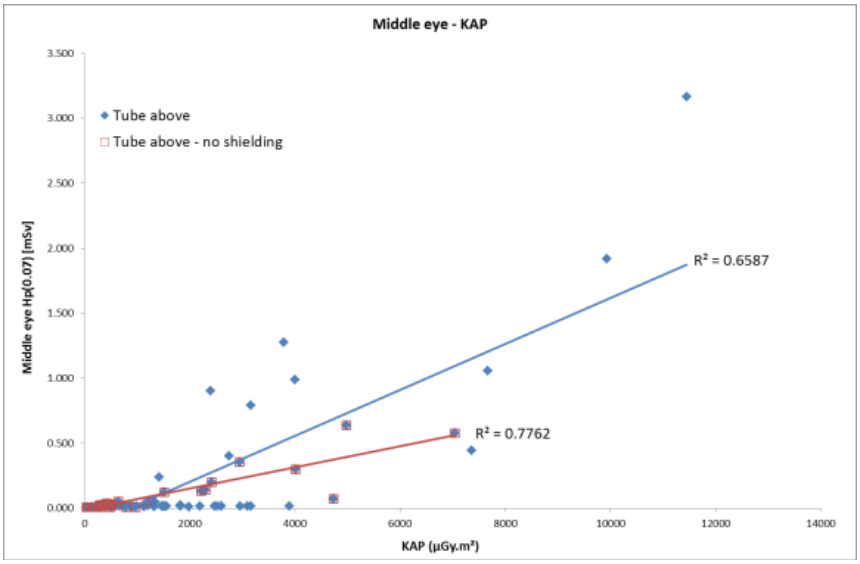
Graph 26: Correlation between the Left leg and KAP values when the tube is below and there is no shield

- *Left eye ↔ KAP (Tube above, Tube above – no shield)*



Graph 27: Correlation between the Left eye and KAP values when the tube is above. Better correlation is observed when the tube is above and there is no ceiling suspended shield

- *Middle eye ↔ KAP (Tube above, Tube above – no shield)*



Graph 28: Correlation between the Left eye and KAP values when the tube is above. Better correlation is observed when the tube is above and there is no ceiling suspended shield

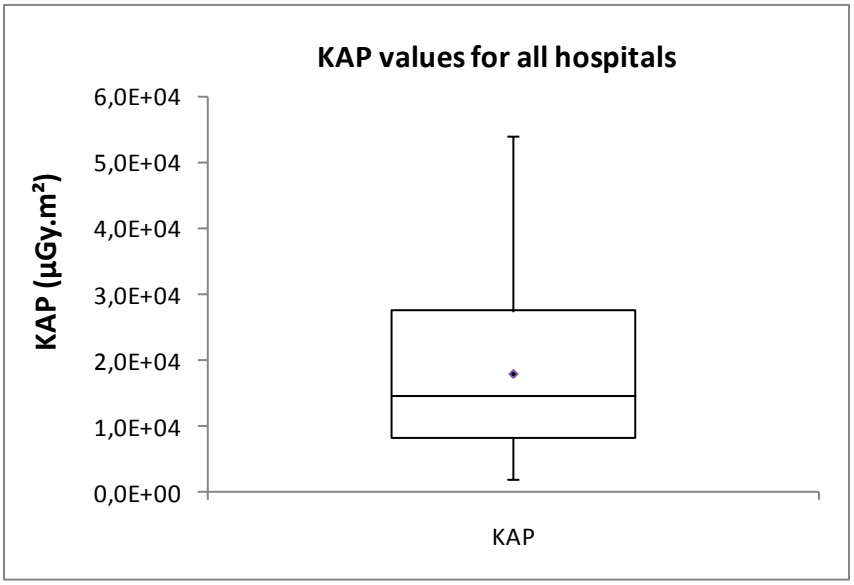
2.1.7 Conclusions

- There is a statistically significant influence of the ceiling suspended shield on finger (1.8 times reduction), wrist (up to 2.5 times) and eye doses (1.6 to 2.2 times), especially for the tube above configurations. However, when the tube is below the table, there is no statistically significant influence of the ceiling suspended shield on finger, wrist and eye doses.
- There is a statistically significant influence of the table shield on leg doses (1.8 times reduction), especially for the tube below configuration. When the tube is above the table, the influence on leg dose exists but it is smaller and not statistically important.
- There is a statistically significant influence of tube configuration. The dose to the fingers, wrists and eyes are lower when the tube is placed below the table. The reduction ratios are 1.5 for the fingers, 2.4 for the wrists and 1.8 for the eyes. Leg doses are higher when the tube is below, by 1.5 to 2 times. The effect is much larger when no shield is used. For data with ceiling shield, the effect of tube configuration on fingers, wrists and eyes is not statistically important.
- It is difficult to predict where the maximum doses are recorded.
- The influence of operator's experience is not clear since there is an interaction between the parameters "experience" and the "tube configuration", so no statistically significant conclusions can be drawn. However, lower doses were found for highly experienced operators for fingers, wrists and legs.

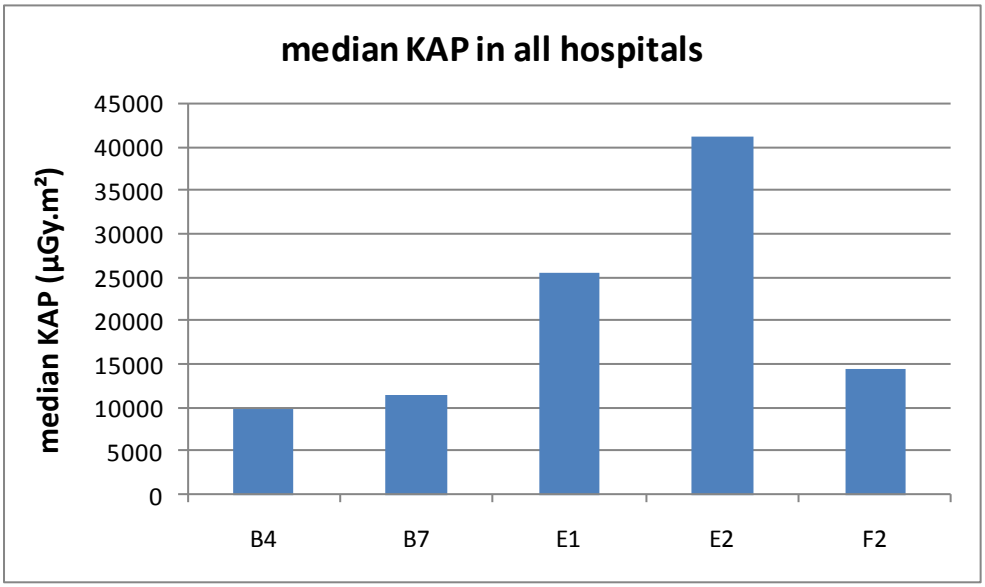
2.2 Angiographies (DSA) and angioplasties (PTA) of the renal arteries (Re)

2.2.1 General information

In total only 31 procedures were monitored in 5 hospitals since the frequency of this procedure is not so high. . The following graph presents a box plot with the respective KAP values and the next graph, the median KAP values at the various hospitals. In 2 hospitals only one measurement was performed and doses were all 'zero'. These 2 measurements were not used for the analysis. All the procedures were performed with a tube-below configuration.

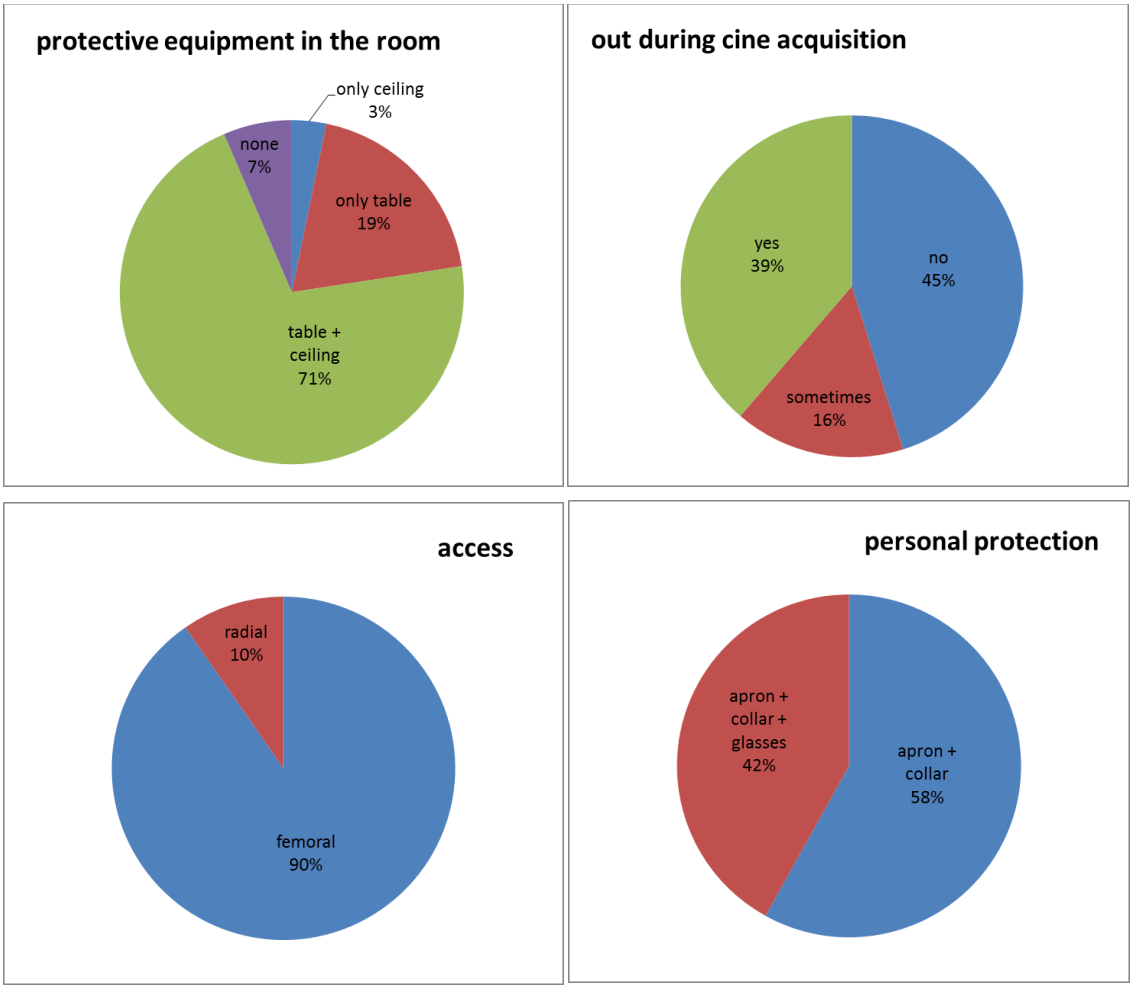


Graph 29: Box plot with the KAP values for the DSA PTA Re procedures



Graph 30: Median KAP values at the various hospitals where the measurement campaign for the DSA PTA Re procedures took place

In the next graphs some statistics are presented giving information about the use of the room protective equipment, personal protective equipment, access of the catheter and whether the operator stays inside or goes outside the room during the image acquisitions.

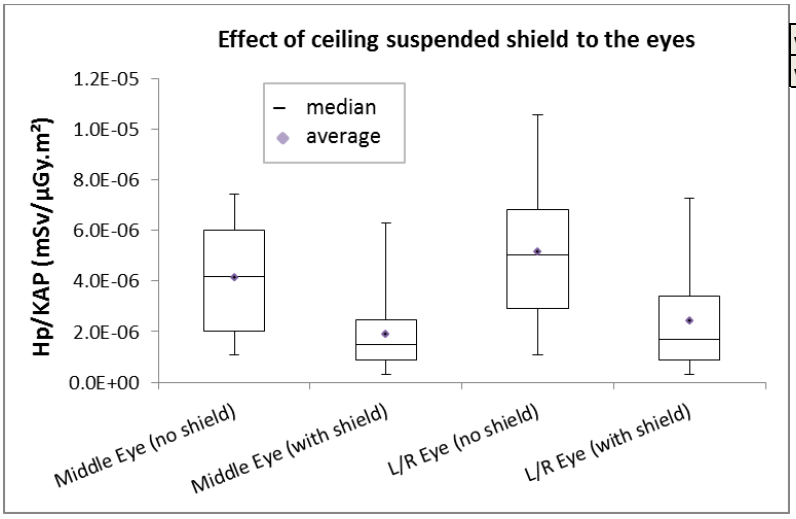


Graph 31: Statistics with the use of the room protective equipment, the personal protective equipment, the access, and whether the operator stays inside or goes outside the room during the image acquisitions

From the above graphs it is seen that all the operators use some kind of personal protective equipment. The femoral access is preferred; and in 7% of the cases there is no room protective equipment. The various H_p/KAP values measured for the DSA PTA Re procedures in each hospital are presented in Appendix 1.

2.2.2 Effect of room protective equipment and the in/out during cine mode parameter

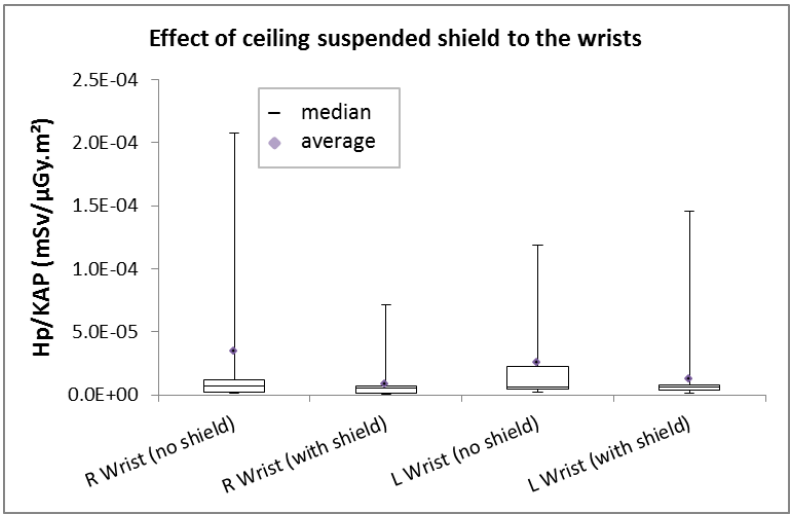
The use of ceiling suspended shield was examined for the effect on the reduction on the eye, finger and wrist doses. The results are presented in the following graphs. The reduction ratio is also calculated using the median values.



with ceiling:	22 cases
without ceiling:	7 cases

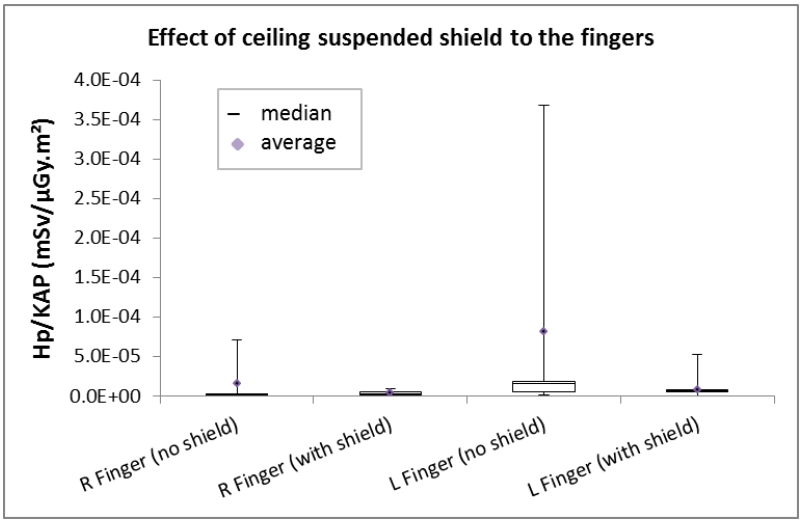
% reduction		
M eye	L eye	
64	67	median
ratio (without/with)		
2.79	3.00	median

Graph 32: The effect of the ceiling suspended shield to the eye doses



% reduction		
R wrist	L wrist	
1	60	median
ratio (without/with)		
1.01	2.49	median

Graph 33: The effect of the ceiling suspended shield to the wrist doses

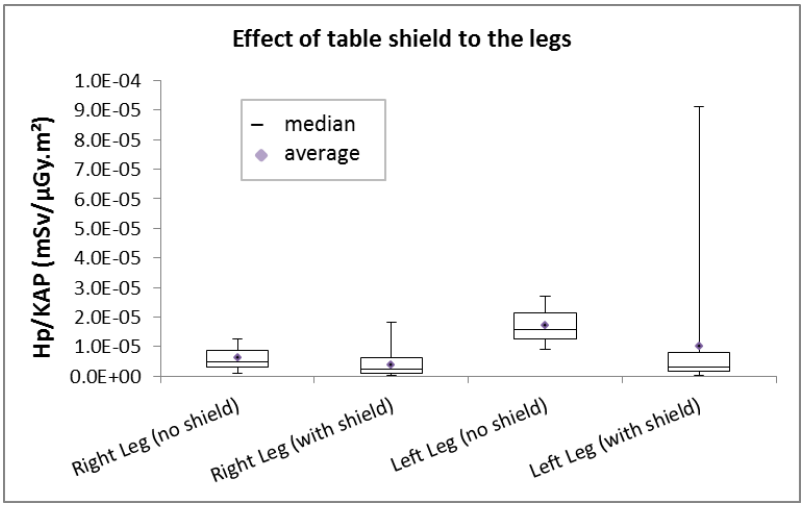


% reduction		
R finger	L finger	
-40	55	median
ratio (without/with)		
0.71	2.20	median

Graph 34: The effect of the ceiling suspended shield to the finger doses

The use of the ceiling suspended shield seems to influence the eye and hand doses, especially the left part. The reduction ratio varies from 1 to 3. For the right finger the influence of the ceiling shield is not seen, since the non shielded median values are lower than the shielded ones.

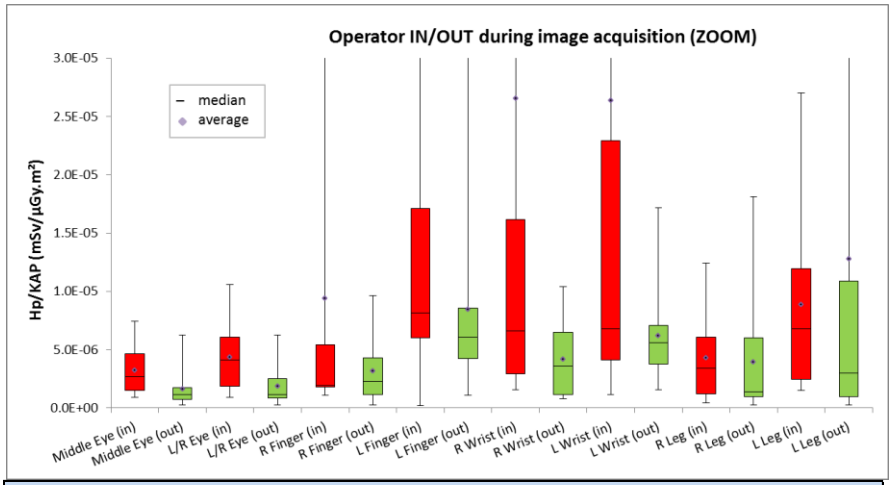
The use of table shield was also studied for the renal DSA and PTA procedures. The following graphs present the influence of the table shield on the leg doses. However, there were only 3 cases without table shield so the conclusions are not considered statistically significant.



% reduction		
R leg	L leg	
52	80	median
ratio (without/with)		
2.10	4.96	median

Graph 35: The effect of the table shield to the leg doses

Finally, the parameter in and out during the image acquisitions was studied for the effect on the extremity and eye lens doses. The following graph presents the $H_p(0.07)$/KAP to the various dosimetric positions for the operators going outside or staying inside during the cine mode. The reduction ratio is also calculated.



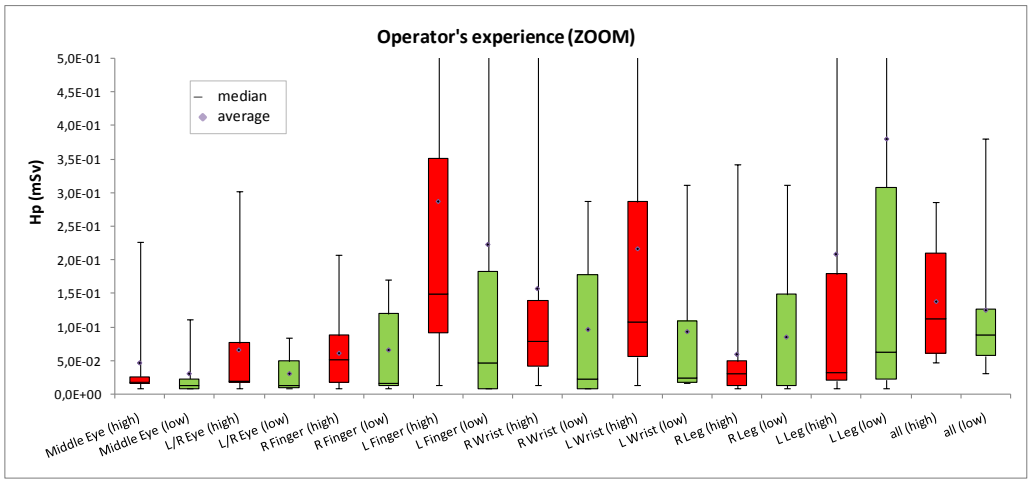
% reduction from OUT							
M eye	L eye	R finger	L finger	R wrist	L wrist	R leg	L leg
58	73	-18	25	46	18	60	56
ratio (IN/OUT)							
2.37	3.65	0.85	1.34	1.84	1.21	2.50	2.27

Graph 36: The H_p/KAP doses for the operator staying inside or going outside during the image acquisition mode

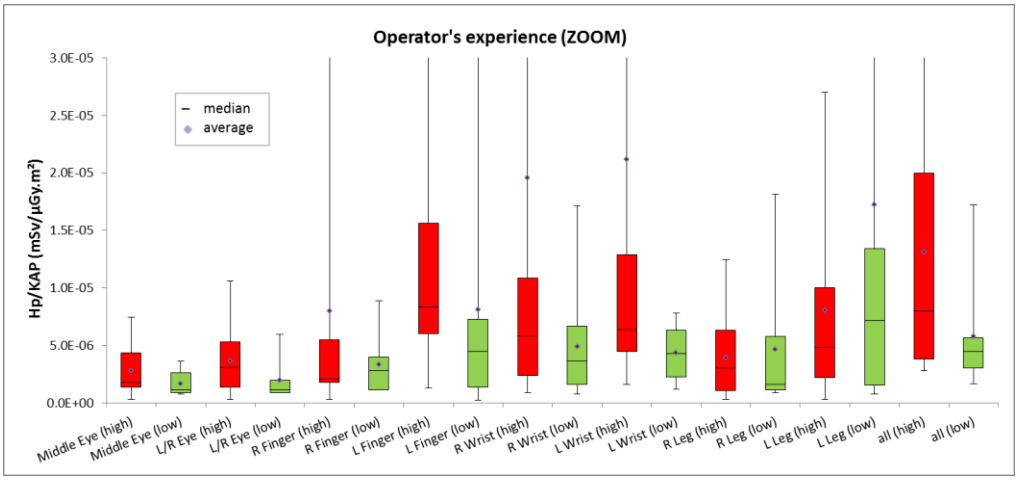
The highest reduction is observed for the eyes and the lowest one for the right finger.

2.2.3 Effect of experience

The effect of the parameter experience is shown in the following two graphs for the H_p and H_p/KAP values.



Graph 37: The effect of the operator's experience on the H_p values

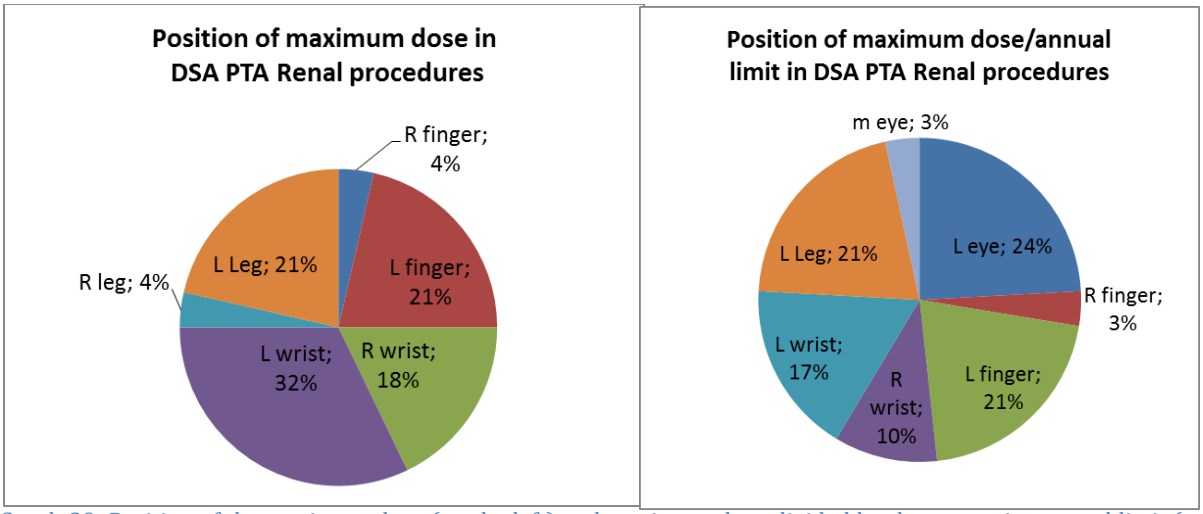


Graph 38: The effect of the operator's experience on the H_p/KAP values (ZOOM graph)

In most of the cases higher doses are observed for the high experienced personnel. This is observed for the H_p and the H_p/KAP values.

2.2.4 Position of the maximum

For the position of the maximum two pie charts are presented: one with the frequency of the position where the maximum dose was recorded and the other with the maximum dose recorded divided by the respective annual limits (150 mSv for the eyes and 500 mSv for the extremities).



Graph 39: Position of the maximum dose (on the left) and maximum dose divided by the respective annual limit (on the right)

The distribution of the position of the maximum is quite large, even when the annual limits are taken into account. From the right graph it is noted that the eyes come into the scene with a frequency of 27%.

2.2.5 Maximum doses

The table with the maximum measured doses is presented in the following. In the table the conditions for which these high doses are observed are described. It is observed that the highest doses were measured when high KAP values are recorded and when the operator stays inside during the cine mode.

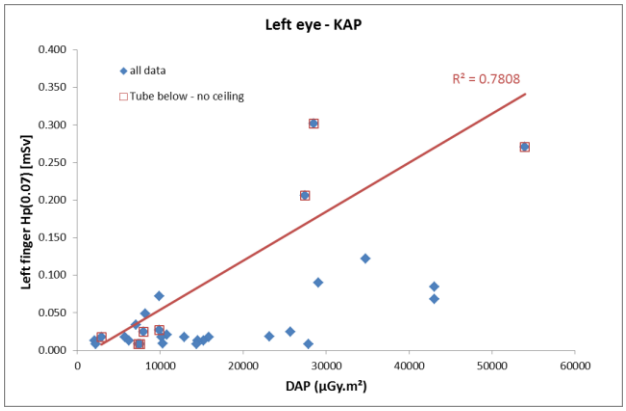
Table 2: The table presents the maximum doses in each dosimetric position and the condition during which these doses were measured

	left eye	middle eye	left finger	right finger	left wrist	right wrist	left leg	right leg
maximum dose [mSv]	0,3	0,2	1,5	0,2	1,0	0,7	2,3	0,3
out during cine	no	no	yes	no	no	no	yes	no
room protection	table	none	table + ceiling	table	table + ceiling	none	table + ceiling	none
access	femoral	femoral	femoral	femoral	femoral	femoral	femoral	radial
KAP [µGy.m²]	28533	53952	43026	2928	7101	53952	25708	27490

2.2.6 Correlations

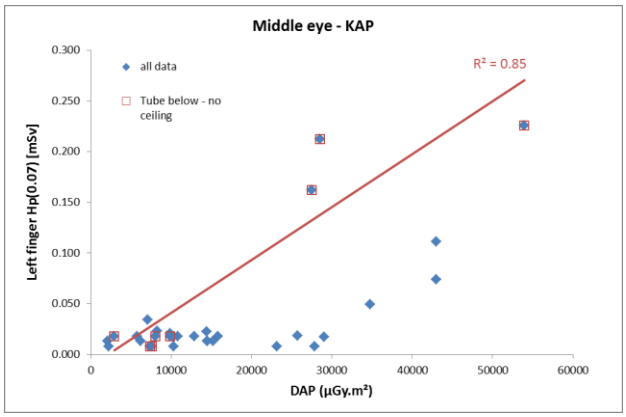
The correlations that were observed are between some dosimetric positions and the respective KAP values:

- *Left eye↔KAP (No ceiling suspended shield)*



Graph 40: Correlation between the Left eye and KAP values when no ceiling suspended shield is used

- *Middle eye↔KAP (No ceiling suspended shield)*



Graph 41: Correlation between the Left eye and KAP values when no ceiling suspended shield is used

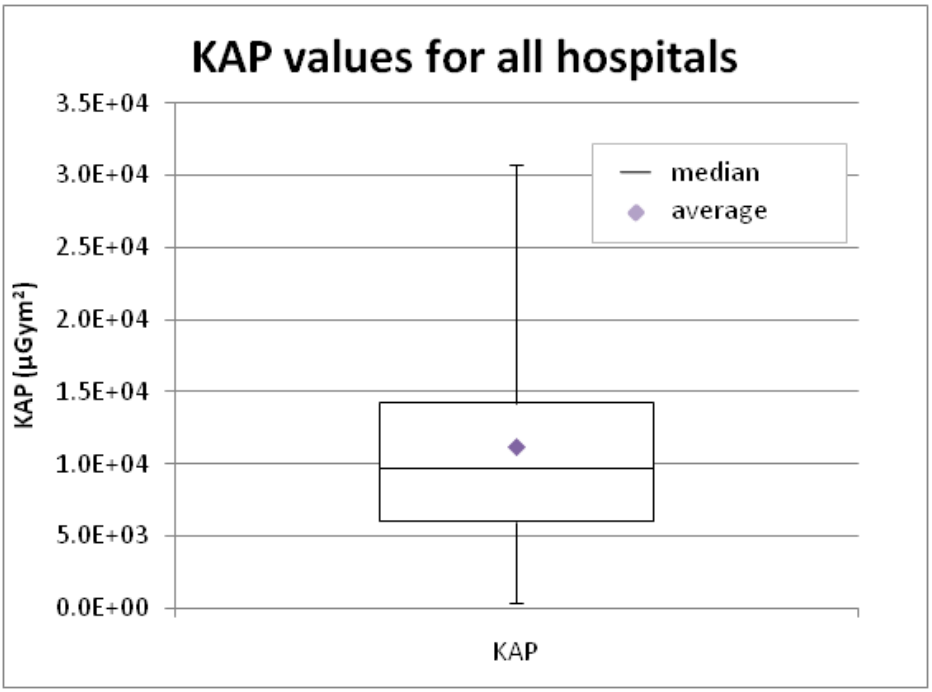
2.2.7 Conclusions

- There is a significant influence of the ceiling suspended shield on eyes, left finger and wrist doses. The reduction ratios are 2.8 to 3 times for the eyes, 2.5 for the wrists and up to 2.2 for fingers.
- There is a significant influence of the table shield on leg doses (2.1 to 5 times). However, only 3 measurements were available without table shield.
- For almost all dosimetric locations, the measured doses are lower for procedures where the operator goes outside during image acquisition. The maximum reduction was observed at the left eye (3.7 times)
- It is difficult to predict where the maximum doses will be measured since a big distribution is observed on the position of the maximum dose.
- Very few correlations were observed; the most important of which were between KAP and eye doses in situations where no ceiling shield is used.

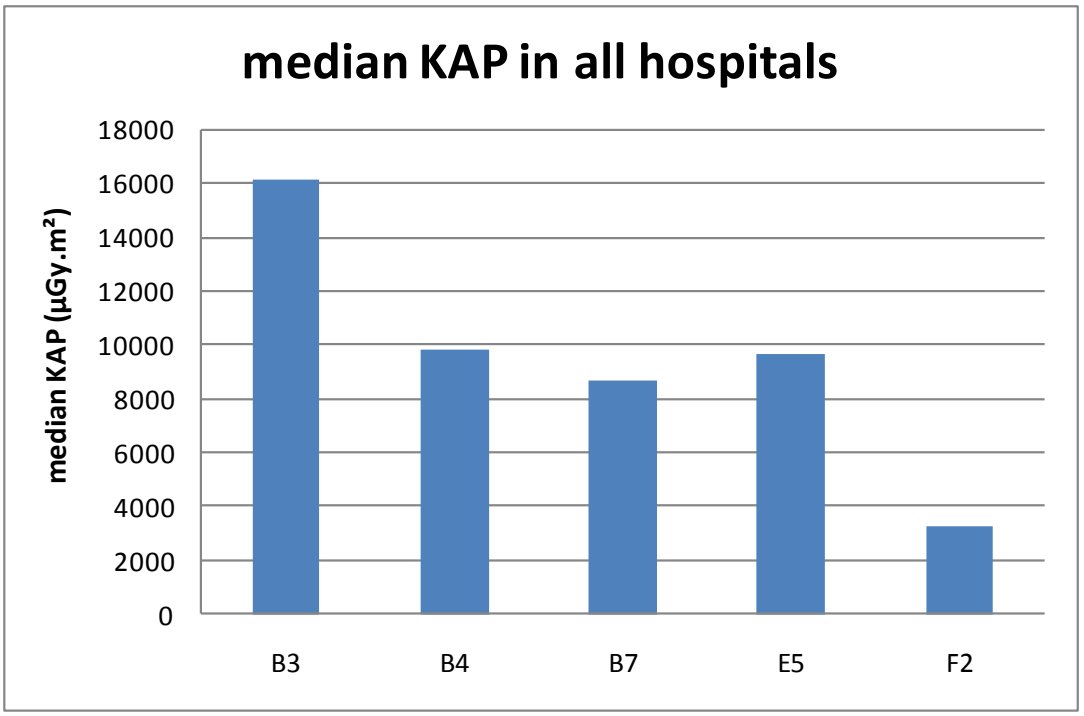
2.3 Angiographies (DSA) and angioplasties (PTA) of the carotids (Ca) and the brain (Ce)

2.2.1 General information

In total 50 procedures were monitored in 5 hospitals. The frequency of this procedure is not so often since it has been substituted by other techniques. The following graphs present the box plot of the respective KAP values and the median KAP values at the various hospitals. In most of the cases room protective equipment were used so no analysis is performed for their effect on the doses due to poor statistics.

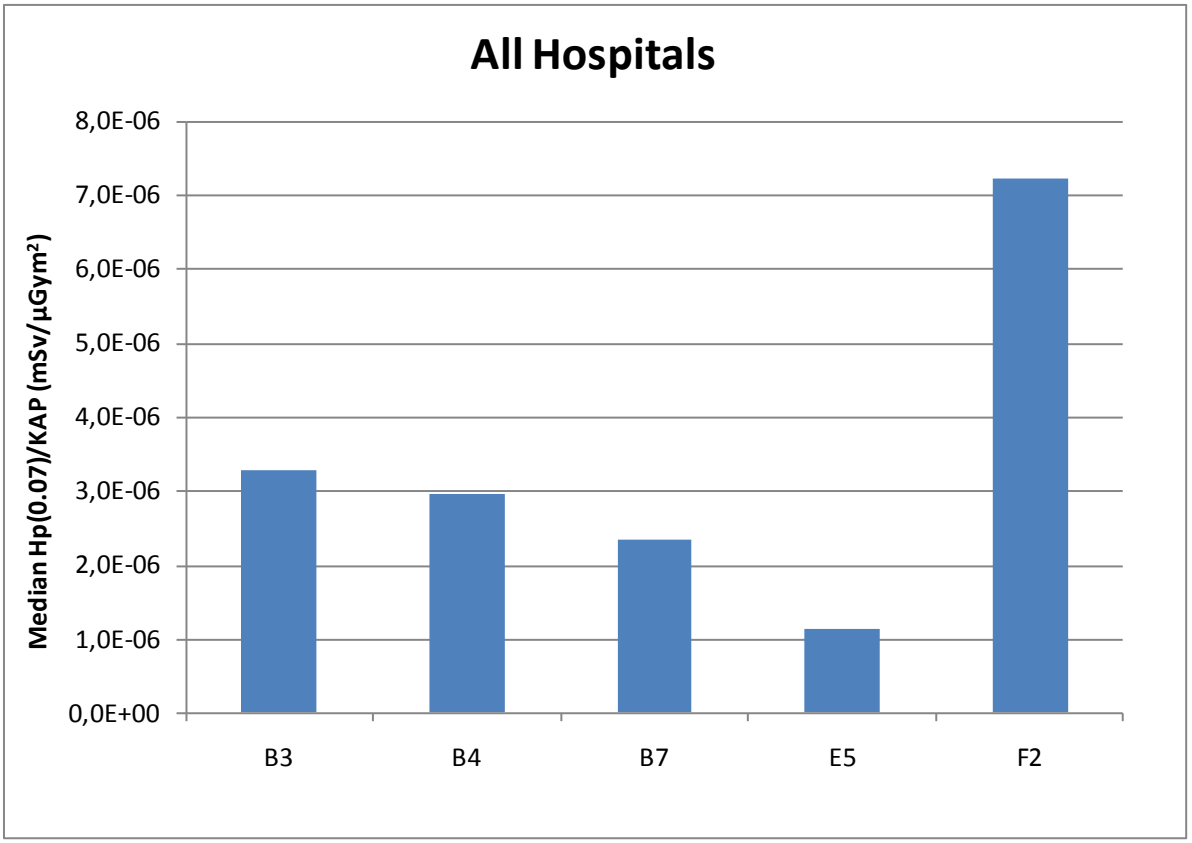


Graph 42: Box plot with the KAP values for the DSA PTA Ca Ce procedures



Graph 43: Median KAP values at the various hospitals where the measurement campaign for the DSA PTA Ca Ce procedures took place

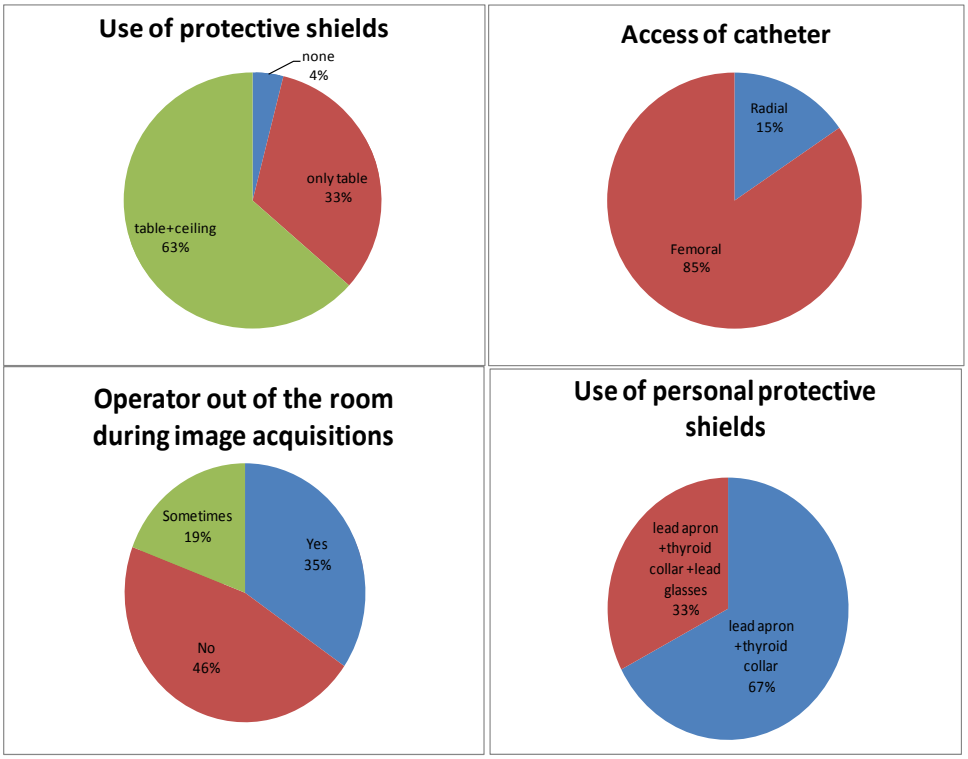
The highest KAP values are recorded at hospital B3 because biplane technique is used in this hospital for this kind of procedures.



Graph 44: Median $H_p(0.07)$/KAP values at the various hospitals where the measurement campaign for the DSA PTA Ca Ce procedures took place

Hospital F2 seems to present the highest doses per KAP, and then hospital B3. Analysing each position separately the highest $H_p(0.07)$/KAP values are recorded at hospital F2 except for the eyes. The highest $H_p(0.07)$/KAP values at the eyes are recorded at hospital B3 which uses the biplane technique for this kind of procedures.

In the next graphs some statistics are presented giving information on the use of the room protective equipment, personal protective equipment, access of the catheter and whether the operator goes out of the room or not during the image acquisitions.



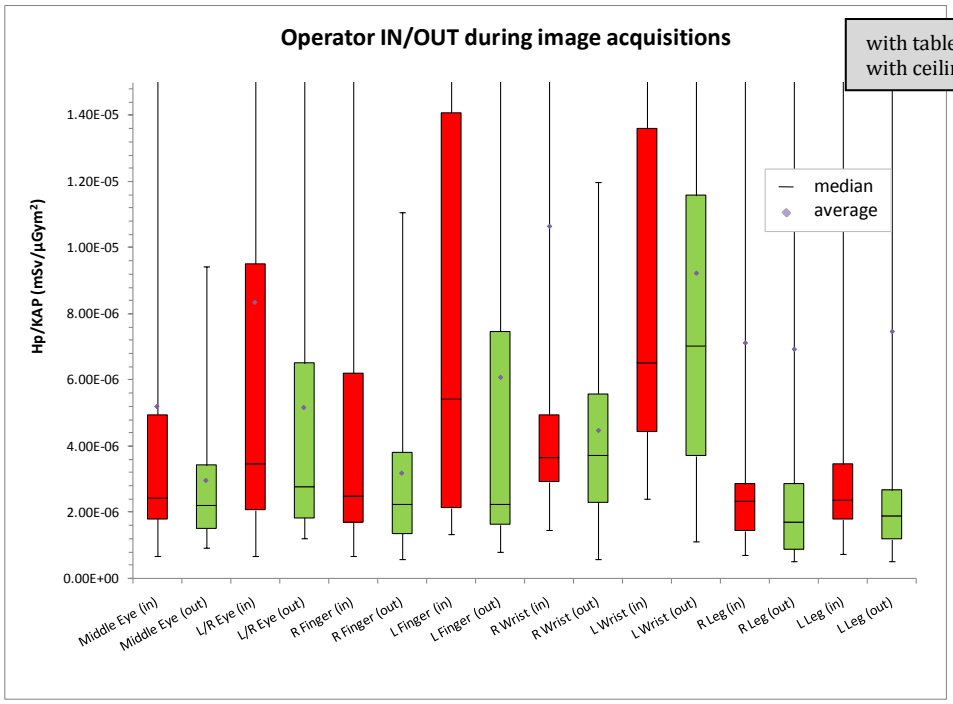
Graph 45: Statistics with the use of the room and personal protective equipment, the access of the catheter, and whether the operator stays inside or goes outside the room during the image acquisitions

As it is seen from the above graphs in 4% of the cases there is no protective equipment. The access of the catheter is femoral in the vast majority of the cases and almost half of the operators (46%) stay inside the room during image acquisitions. Finally all the operators wore a lead apron and a thyroid collar but only 33% of them wore lead glasses.

The various H_p/KAP values measured for the DSA PTA Re procedures in each hospital are presented in Appendix 1.

2.3.2 Effect of the parameters going outside or staying inside the room during image acquisitions, tube configuration and access

In the following graph the doses at the various procedures are presented for the different cases depending if the operator stays inside the room or goes outside when the cine mode is used. Only the shielded measurements are analysed, because the sample of the non shielded cases is small.

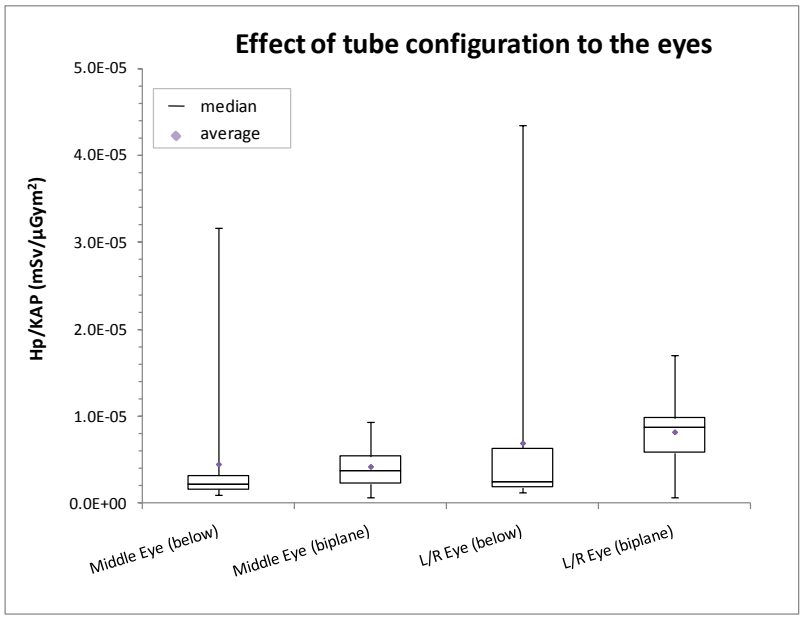


% reduction from out							
M eye	L eye	R finger	L finger	R wrist	L wrist	R leg	L leg
8%	20%	10%	59%	-1%	-8%	27%	20%
ratio (IN/OUT)							
1.09	1.24	1.11	2.42	0.99	0.93	1.36	1.25

Graph 46: The H_p/KAP doses for the personnel going out or staying inside during the image acquisition mode (ZOOM graph). Ceiling and table shield are present.

The H_p/KAP values in all positions are generally higher when the operator stays inside during image acquisitions. The dose reduction when the operator goes outside the room is more significant to the left finger because then the operator uses an automatic contrast injection system. There are no clear results for the wrists which probably has to do with how well the ceiling shield was positioned.

The effect of tube configuration was studied in DSA PTA Ca and Ce procedures. The following graph presents the effect of tube configuration.



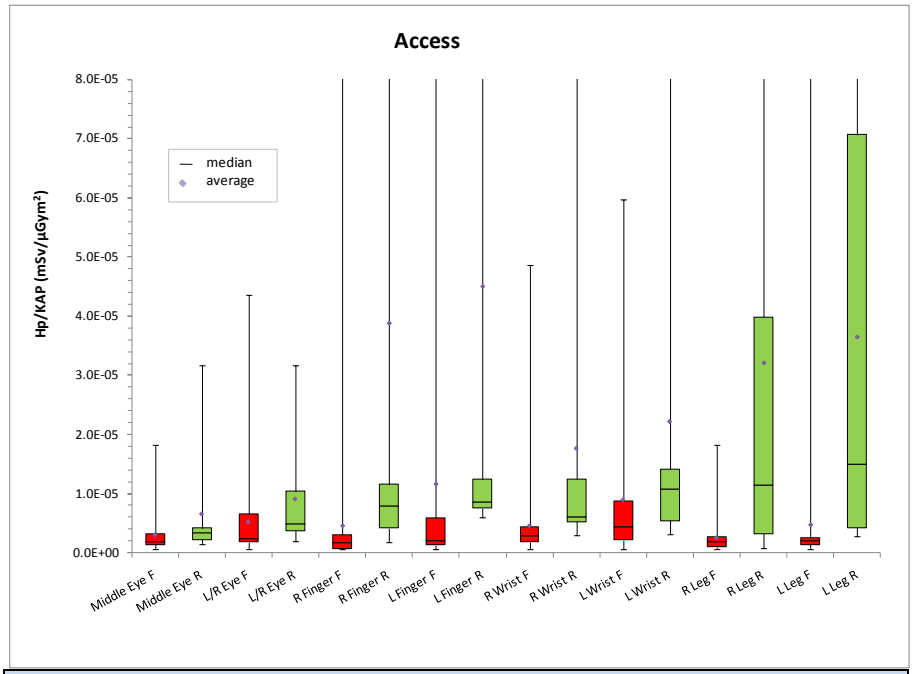
tube below: 25 cases
biplane: 8 cases

% (biplane-below/biplane)		
M Eye	L Eye	
43%	72%	**median**
Ratio (biplane/below)		
1.76	3.63	median

Graph 47: The effect of tube configuration to the eye doses

As it is seen from the above graph and table the tube configuration is an important factor for the eye doses. In the biplane cases the left eye doses are 3.6 times higher than in the cases where the tube is placed below the operating table.

The effect of the access of the catheter was also examined for the doses measured in DSA PTA Ca Ce procedures.



RADIAL: 8
FEMORAL: 44

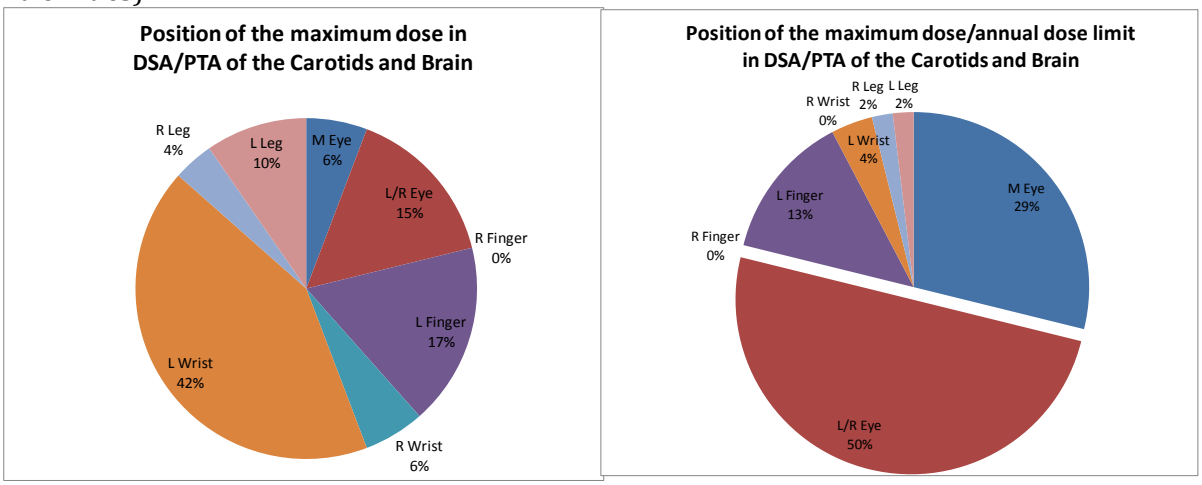
(RADIAL-FEMORAL)/RADIAL							
M eye	L eye	R finger	L finger	R wrist	L wrist	L leg	R leg
44%	50%	78%	77%	51%	59%	84%	87%
RATIO RADIAL/FEMORAL							
1.78	2.00	4.54	4.39	2.04	2.42	6.22	7.48

Graph 48: The effect of the access of the catheter to the doses of the various dosimetric positions (ZOOM graph)

All doses are significantly increased for radial access. For the legs the difference is high because the operator's legs were not always behind the table shield or there was no table shield at all.

2.3.3 Position of the maximum dose

For the position of the maximum two pie charts are presented: one with the frequency of the position where the maximum dose was recorded and the other with the maximum dose recorded divided by the respective annual limits (150 mSv for the eyes and 500 mSv for the extremities).



Graph 49: Position of the maximum dose (on the left) and maximum dose divided by the respective annual limit (on the right)

The maximum dose was recorded on the left wrist and on the left finger most of the times. However, taking into account the annual limits for all positions the exposure to the eye lens seems to be the most important (79%).

2.3.4 Maximum doses

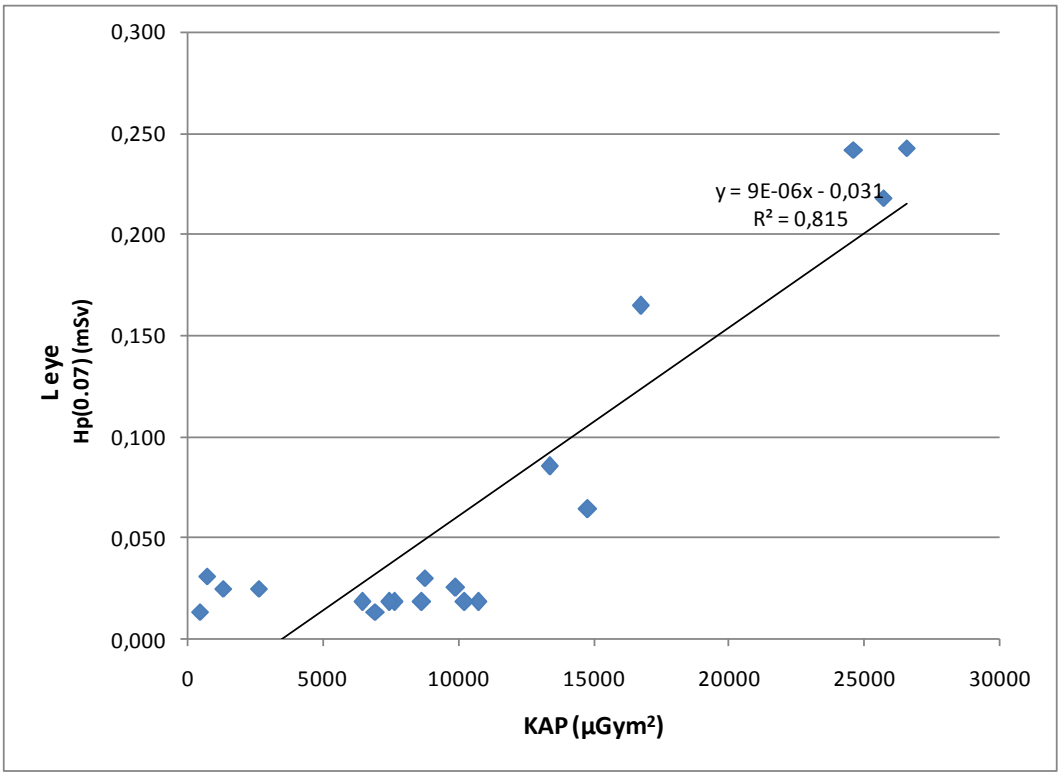
The following table presents the maximum doses and the respective conditions during which these doses were measured.

	L Finger	R Finger	L Wrist	R Wrist	L Leg	R Leg	L/R Eye	Middle Eye
Maximum Dose (mSv)	0.38	0.10	0.35	0.11	0.23	0.37	0.28	0.17
Protective equipment	Table	table+ceiling	table+ceiling	none	table		table+ceiling	
Out during image acquisitions	Yes	no	sometimes	sometimes	sometimes		no	
Tube configuration	Below	biplane	below	below	below		biplane	
KAP (µGym^2)	3948	14780	13930	8230	3261		16150	
Comments	no ceiling shield	ceiling shield only covered the lateral tube	low experience	radial access - no shields	radial access - operator did not always stand behind the shield			

2.3.5 Correlations

The parameters that were checked to be in good correlation are between the Left eye dose and the KAP values.

- *Left eye↔KAP (IN during acquisitions, Ceiling suspended shield present)*



Graph 50: Correlation between the Left eye and KAP values when the ceiling suspended shield is present and the operator stays inside the operating room during the image acquisitions

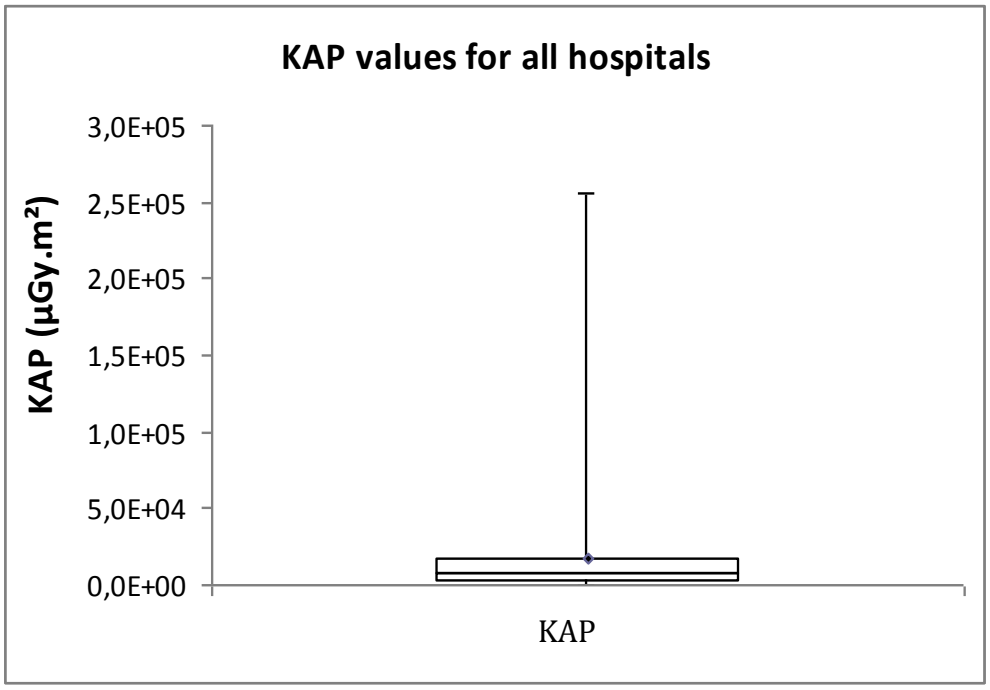
2.3.6 Conclusions

- Effect of the parameter staying inside or going outside the room during image acquisitions: the H_p/KAP values in all positions are generally higher when the operator stays in the room during image acquisitions. As expected, the dose reduction when the operator goes outside the room during acquisitions is more significant to the fingers (Left finger dose reduction 60%) because an automatic contrast injection system is usually used.
- Effect of tube configuration: for these procedures the tube was always below or a biplane system was used. As there were only 8 cases when biplane technique was used (with shields present in the room) the results are not clear. However, it seems like the dose to the eyes increases (up to 72%) when using this technique, probably because the ceiling shield was not positioned correctly and/or was not adequately covering both tubes. An additional shield is advised in this case.
- Access: Not statistically important conclusions can be drawn due to poor statistics for the effect of the access. There were only 8 cases for radial access of the catheter and they were performed under different conditions. However, when all the cases were included (operator IN and OUT, WITH and WITHOUT shield) the doses are significantly lower when femoral access is used. For the radial access the doses to the fingers increase up to 77% when compared with the ones for femoral access.
- Location of the maximum: the maximum dose was recorded on the left wrist and then on the left finger most of the time. However, taking into account the annual limits for all positions special attention should be given for the eye lens.

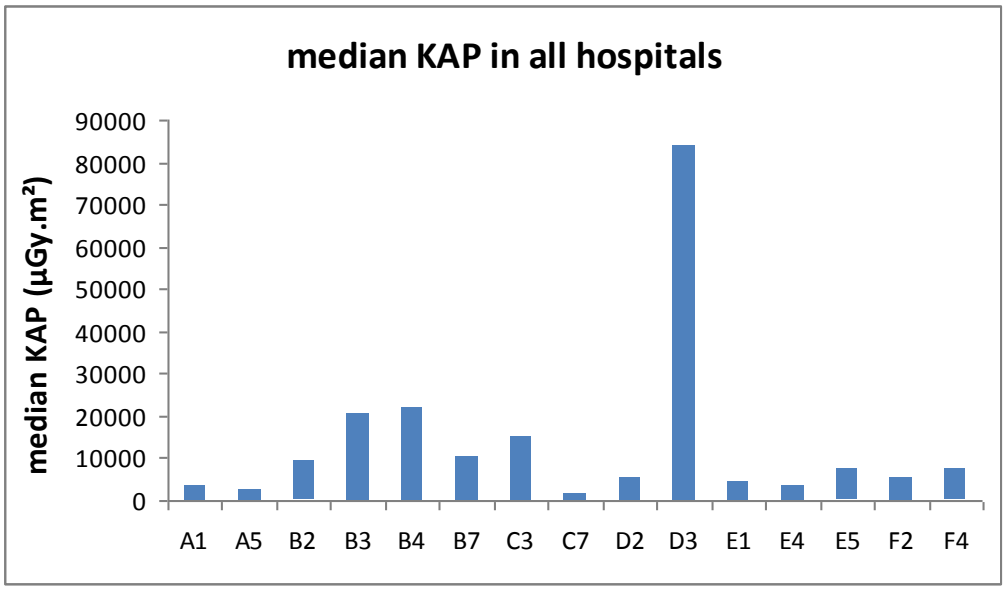
2.4 *Angiographies (DSA) and angioplasties (PTA) of the Lower Limbs (LL)*

2.4.1 General information

In total 169 procedures were monitored in 15 hospitals. The following graphs present the box plot with the respective KAP values and the next one the median KAP values at the various hospitals.



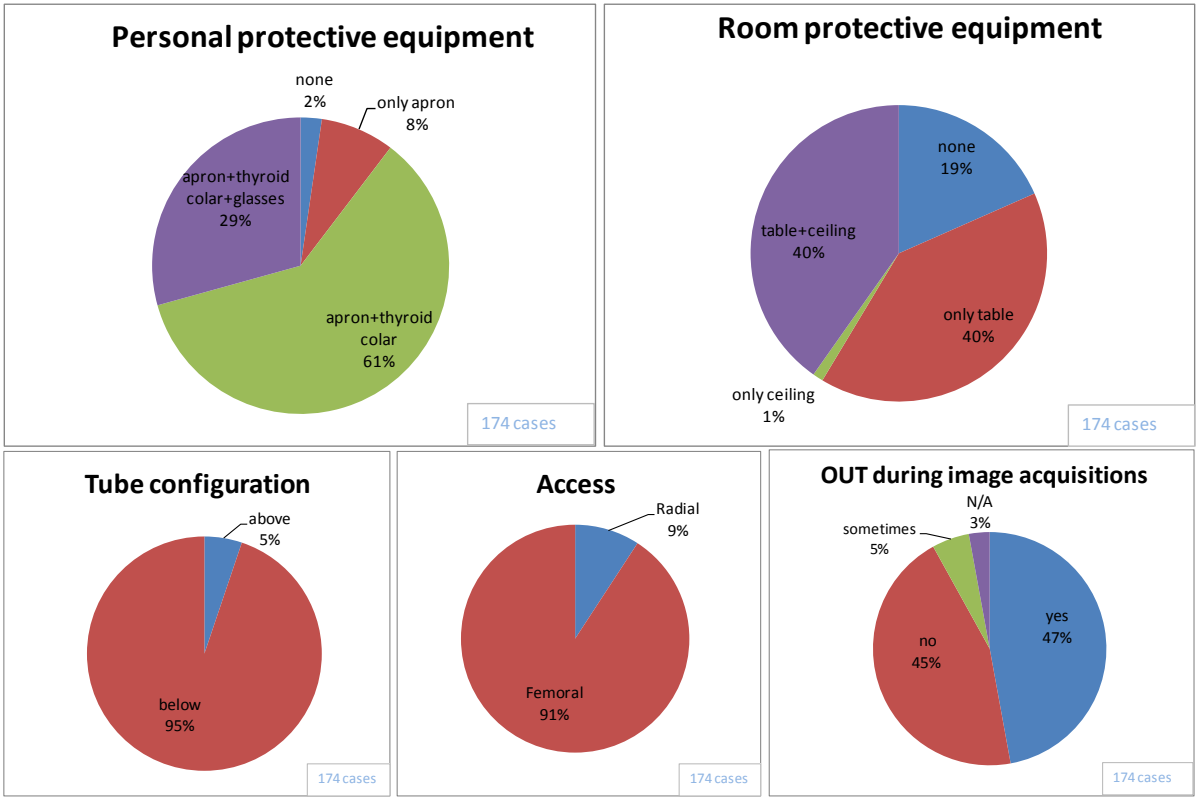
Graph 51: Box plot with the KAP values for the DSA PTA LL procedures



Graph 52: Median KAP values at the various hospitals where the measurement campaign for the DSA PTA LL procedures took place

In D3 hospital some very complex procedures were performed and due to this the median KAP values are very high.

In the next graphs some statistics are presented giving information on the use of the room and personal protective equipment, tube configuration, access of the catheter and whether the operators go outside the room or not during the image acquisitions.

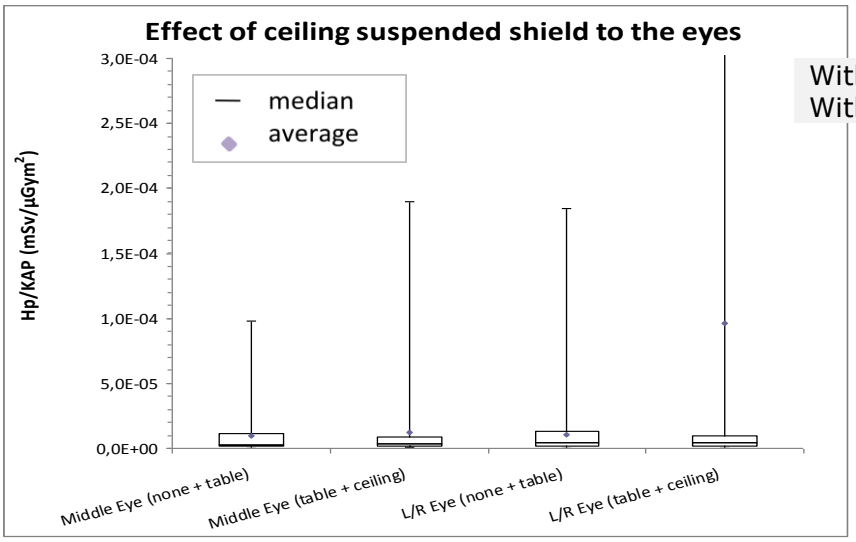


Graph 53: Statistics with the use of the room and personal protective equipment, the tube configuration, the access of the catheter and whether the operators go outside the room or not during the image acquisitions

The various H_p/KAP values measured for the DSA PTA LL procedures in each hospital are presented in Appendix 1.

2.4.2 Effect of room protective equipment, tube configuration and in/out during cine parameter

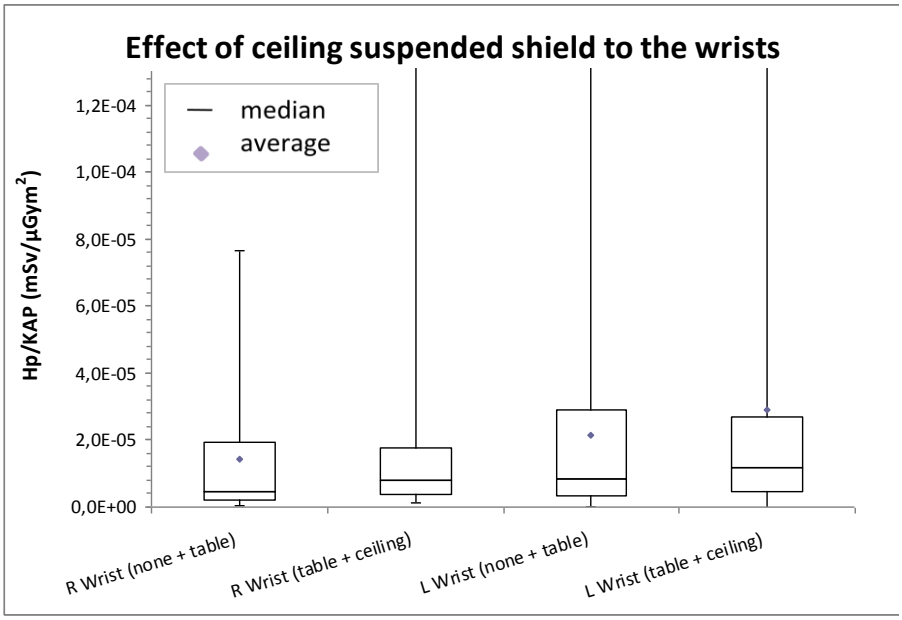
The use of ceiling suspended shield was studied for the effect on the reduction of the eye, finger and wrist doses. The results are presented in the following graphs. The reduction ratio is also calculated.



With ceiling	72 cases
Without ceiling	97 cases

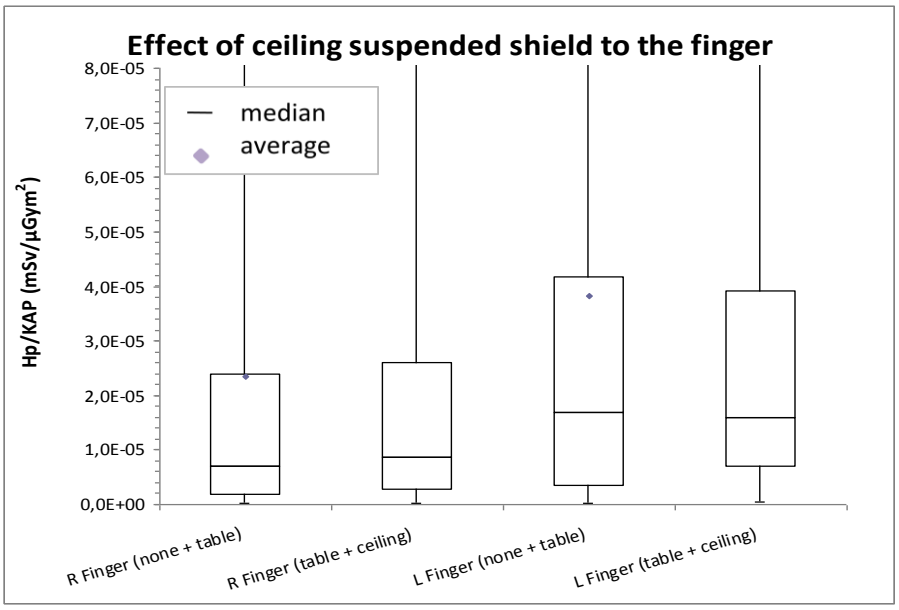
% reduction		
	M eye	L eye
median	-19,46	-0,12
ratio (without/with)		
median	0,84	1,00

Graph 54: The effect of the ceiling suspended shield to the eye doses



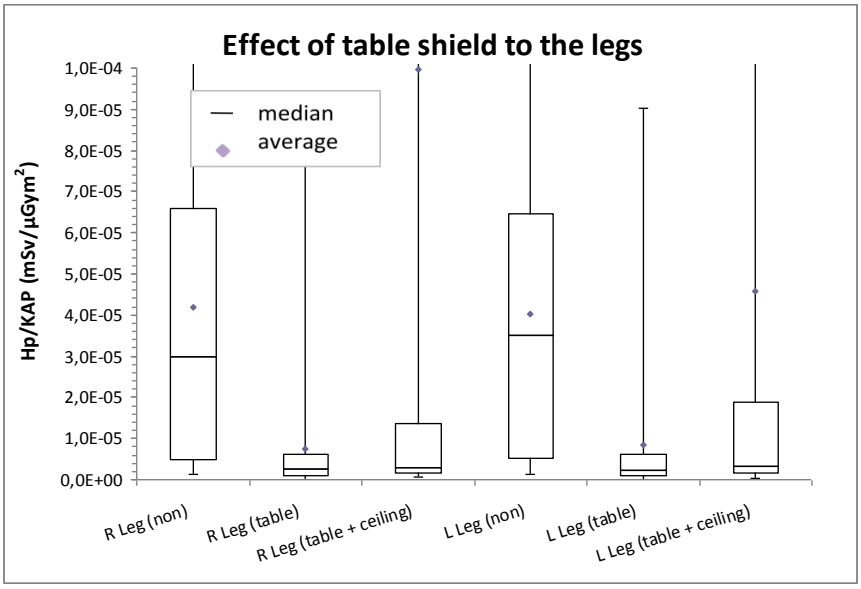
% reduction		
	R wrist	L wrist
median	-73	-44
ratio (without/with)		
median	0,58	0,69

Graph 55: The effect of the ceiling suspended shield to the wrist doses (ZOOM graph)



% reduction		
	R finger	L finger
median	-22	6
ratio (without/with)		
median	0.82	1.06

Graph 56: The effect of the ceiling suspended shield to the finger doses

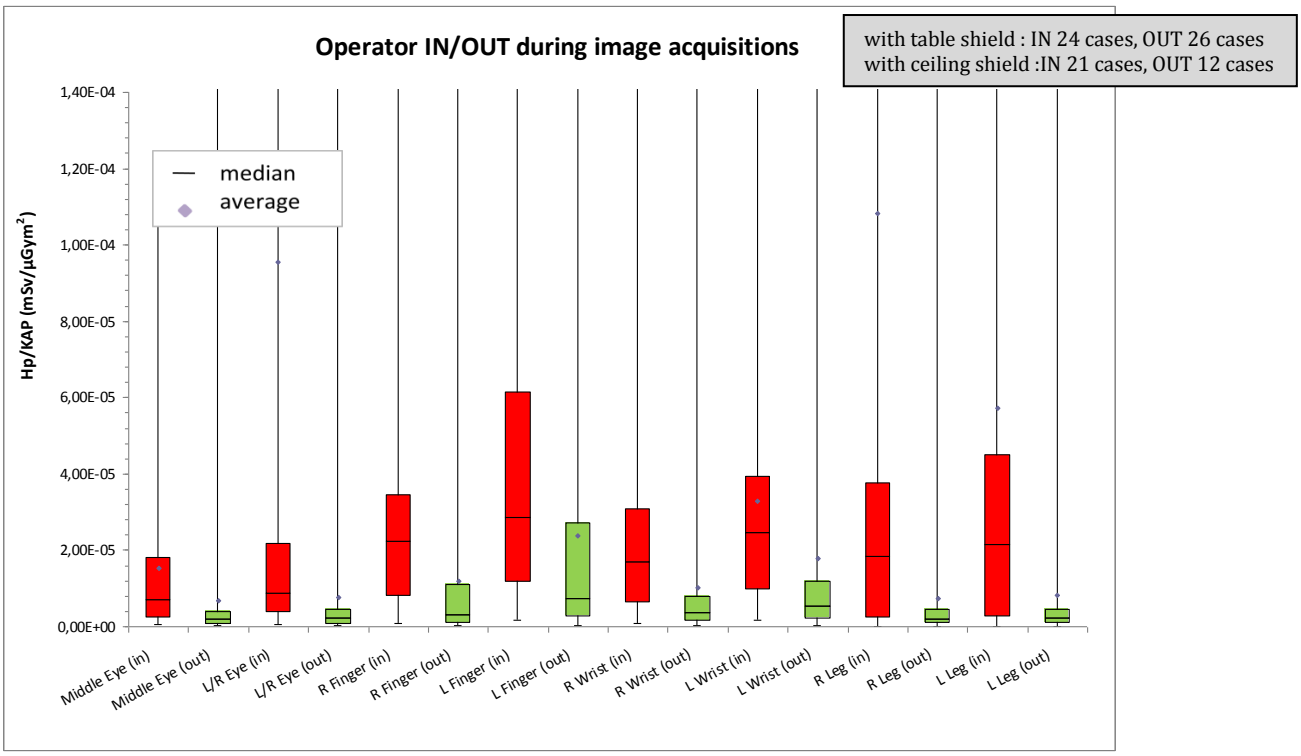


% reduction		
	R leg	L leg
median	26	10
ratio (without/with)		
median	1.36	1.11

Graph 57: The effect of the table shield to the leg doses (ZOOM graph)

As it is seen from the above graphs we reach to contradictory conclusions about the influence of the ceiling suspended shield for the eyes, wrist and finger doses. The doses, when the shield is used, seem to be higher than the ones when the ceiling shield is not used. This is because, according to the parameter analysis, there is a strong interaction between the parameters "ceiling shield" and "going out during the cine mode". Therefore, the ceiling effect should be investigated by separating the cases when the operator goes outside the room or stays inside during the cine mode. However, even when we did that, there was a small effect of the ceiling shield (not significantly lower values when the ceiling is used). This small effect of the ceiling shield in lowering the doses is due to the fact that most procedures are performed with the tube below the operating table.

As far as the leg doses are concerned, the above graph shows that there is a 10 to 26% reduction of the leg doses when the table shield is used. When checking the interactions, no interaction was found between the "going out during cine mode" parameter and the "table shield" so the conclusions can be considered significantly important.



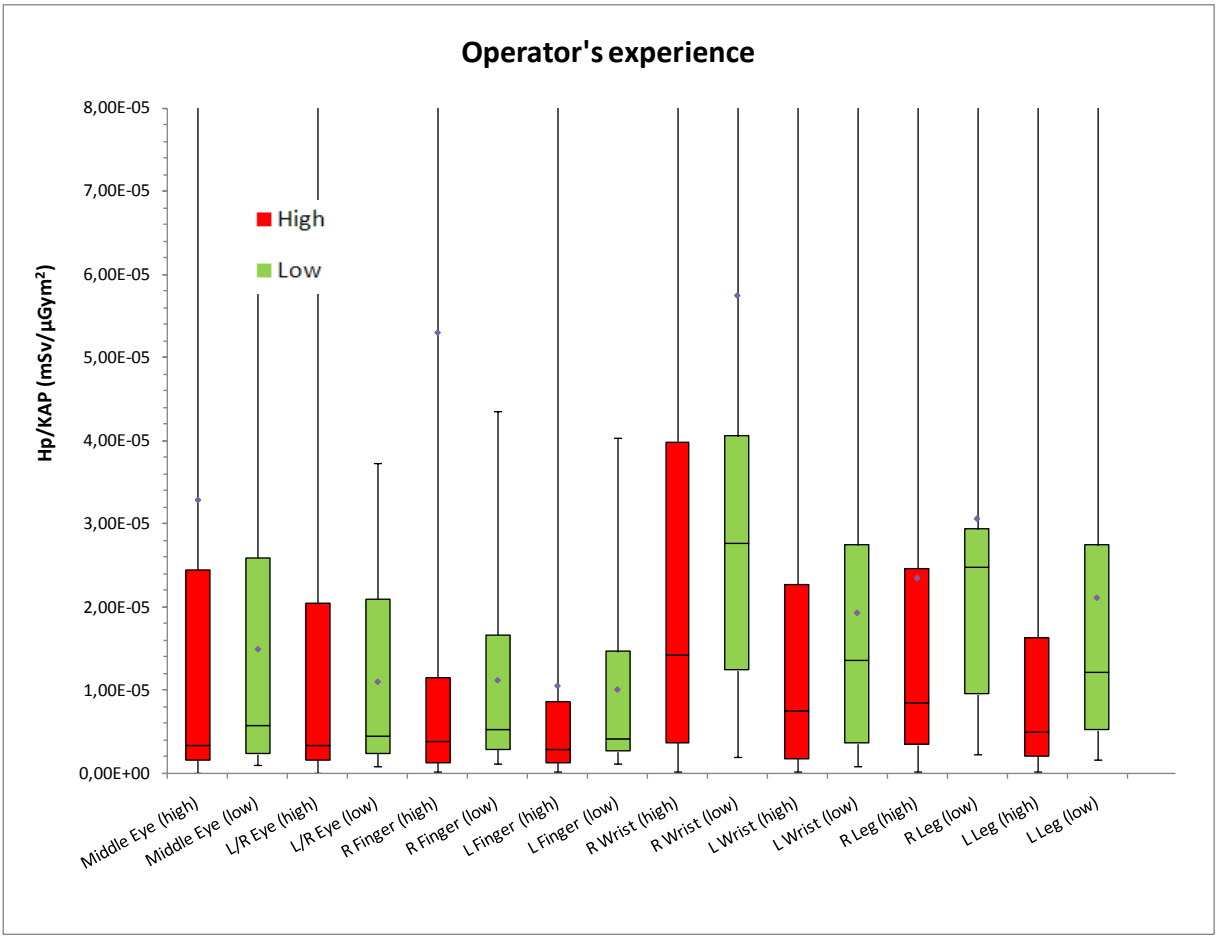
% reduction from out							
M eye	L eye	R finger	L finger	R wrist	L wrist	R leg	L leg
75,3	74,1	85,6	73,0	82,4	80,4	93,6	94,0
ratio (IN/OUT)							
4,04	3,86	6,96	3,71	5,7	5,11	15,7	16,7

Graph 58: The H_p/KAP doses for the personnel going out or staying inside during the image acquisitions(zoom graph).

There is a significant effect of the "going out during cine" parameter in reducing the doses in all dosimetric positions examined.

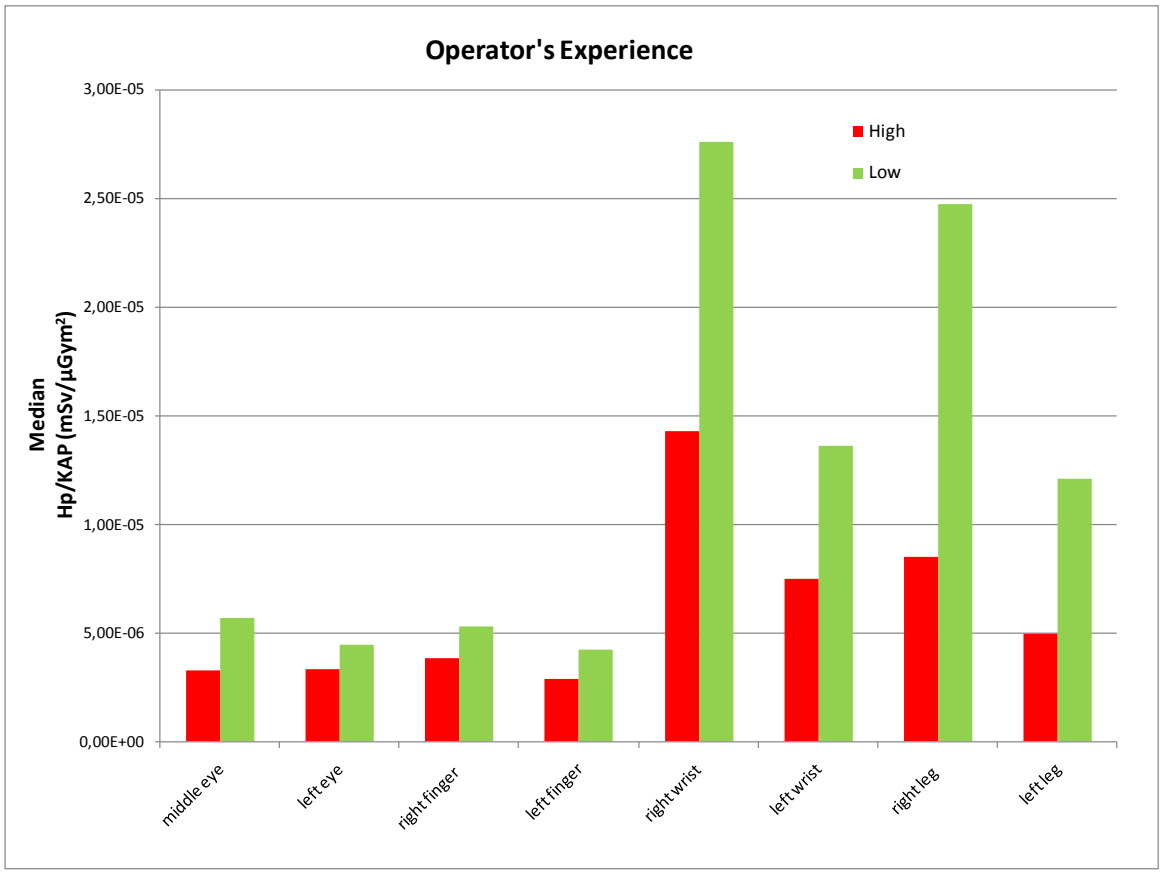
2.4.3 Effect of experience

The experience of the operator was considered as one factor that may affect the doses. The following graphs present the doses to the various dosimetric positions for high and low experienced personnel for the H_p/KAP values.



Graph 59: The effect of the operator's experience on the Hp/KAP values (ZOOM graph)

The median values for the various positions are also presented in the following graph.

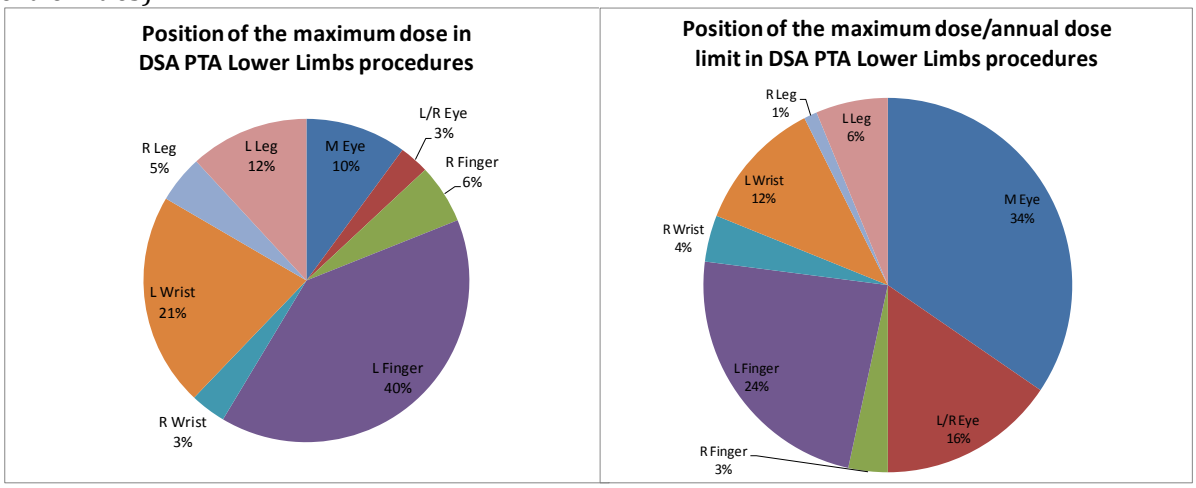


Graph 60: The median H_p/KAP values for high and low experienced operators.

From the above graphs slightly lower H_p/KAP values are observed for operators with high experience. For median values, all dosimetric positions have lower doses for high experienced personnel. However, as it was proven from the ANOVA analysis the significance of experience on the doses cannot be considered statistically important.

2.4.4 Position of the maximum

For the position of the maximum two pie charts are presented: one with the frequency of the position where the maximum dose was recorded and the other with the maximum dose recorded divided by the respective annual limits (150 mSv for the eyes and 500 mSv for the extremities).



Graph 61: Position of the maximum dose (on the left) and maximum dose divided by the respective annual limit (on the right)

From the above graph it is shown that the position of the maximum is observed on the left finger and then the left wrist. When the annual limits are taken into account the exposure of the eyes is the highest (34% and 16% for the middle eye and left eye respectively).

2.4.5 Maximum doses

A table with the maximum doses measured in our study is presented. In the table the conditions that these high doses are observed are described.

Table 3: The table presents the maximum doses in each dosimetric position and the conditions during which these doses were measured

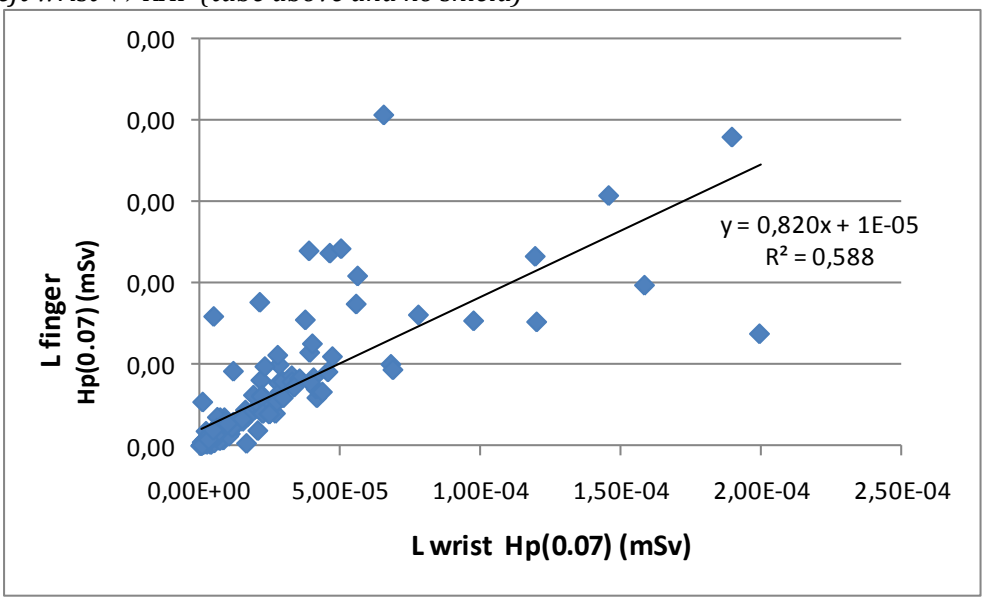
	L Finger	R Finger	L Wrist	R Wrist	L Leg	R Leg	L/R Eye	Middle Eye
Maximum Dose	4.02	0.86	1.7	0.1	0.5	0.35	0.66	0.05
Protective equipment	None	table+ceiling	table+ceiling	None	None	None	Table	Table
Out during image acquisitions	No	Yes	No	Sometimes	No	No	No	Yes
Tube configuration	Above	Below	Below	Below	Below	Below	Below	Below
KAP (μGym^2)	5670	36933	10900	8230	1400	1965	70320	41523

From the table it is seen that most of the maximum doses were measured when no room protective equipment was used and when the operator did not leave the room during image acquisitions.

2.4.6 Correlations

The only correlations that were observed are between some dosimetric positions and the respective KAP values.

- *Left wrist ↔ KAP (tube above and no shield)*



Graph 62: Correlation between the Left wrist and Left finger values when the tube is below the operating table

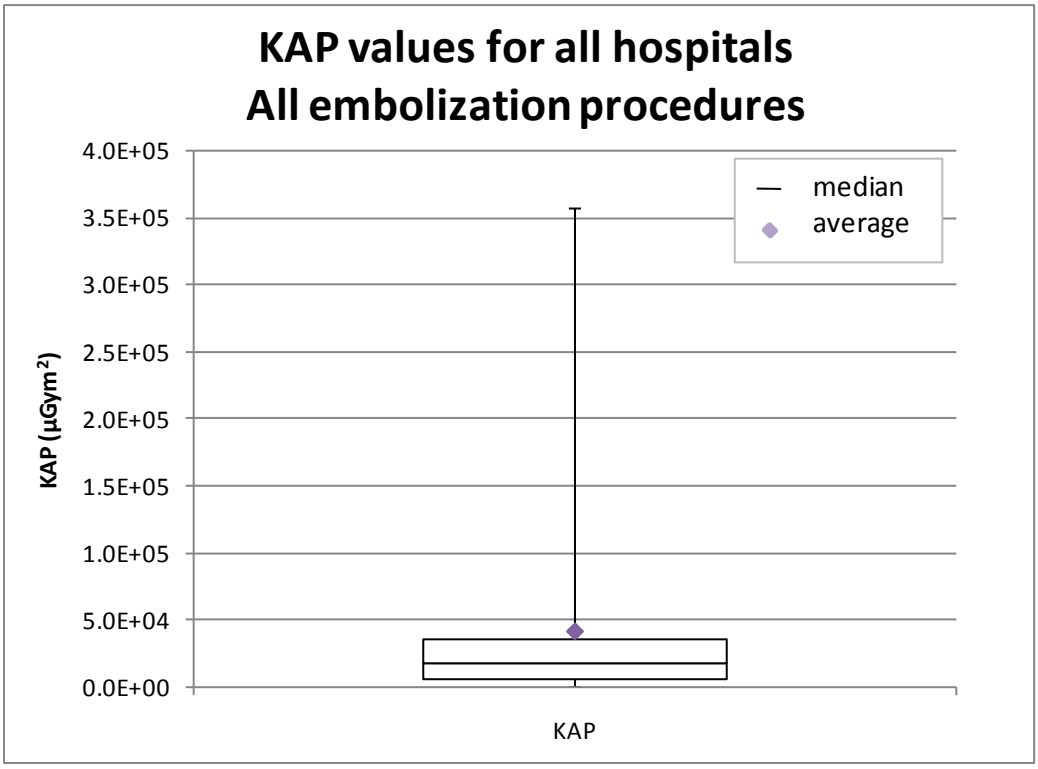
2.4.7 Conclusions

- There is no significant effect from the ceiling suspended shield on the eye, wrist and finger doses due to the fact that most of the procedures are performed with the tube below the operating table
- The table shield has a statistically significant effect on reducing the leg doses when used (10 to 26% reduction)
- There is a significant effect on the doses to all positions, when the operator uses the automatic contrast injector and leaves the room during the cine mode. The highest reduction is observed for the legs (16 times)
- There is no major effect from operator's experience

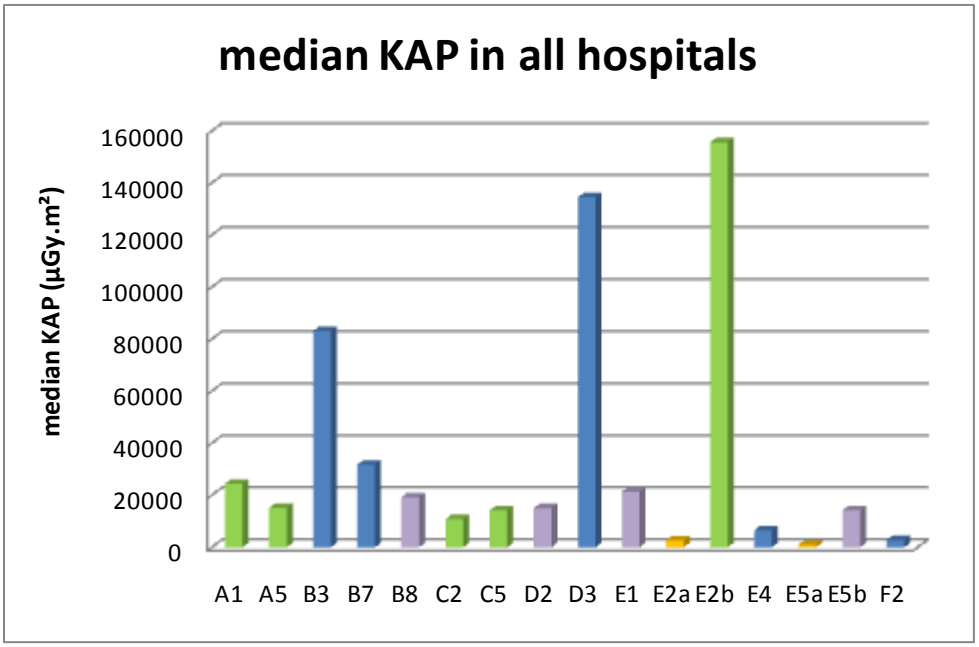
2.5 Embolizations

2.5.1 General information

In total 174 procedures were monitored in 14 hospitals. There is a large distribution on the type of the embolizations that were monitored: chemoembolizations (25%), neuroembolizations (26%), renal embolisations, embolisations of the spermatic vein (12%) and embolisations for bleeding control. The following graph presents the box plot with the respective KAP values and the next one, the median KAP values at the various hospitals.

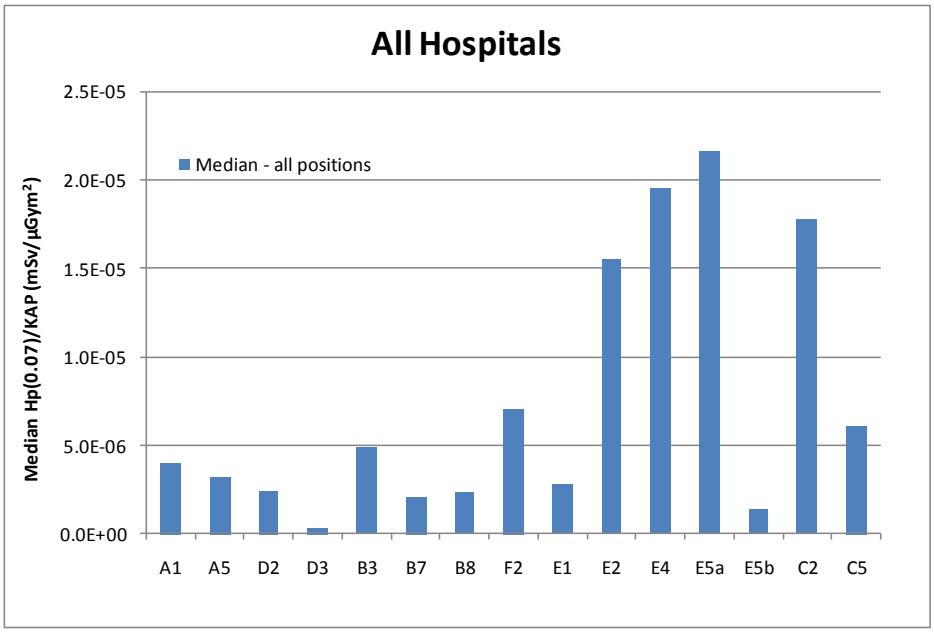


Graph 63: Box plot with the KAP values for all the monitored embolization procedures



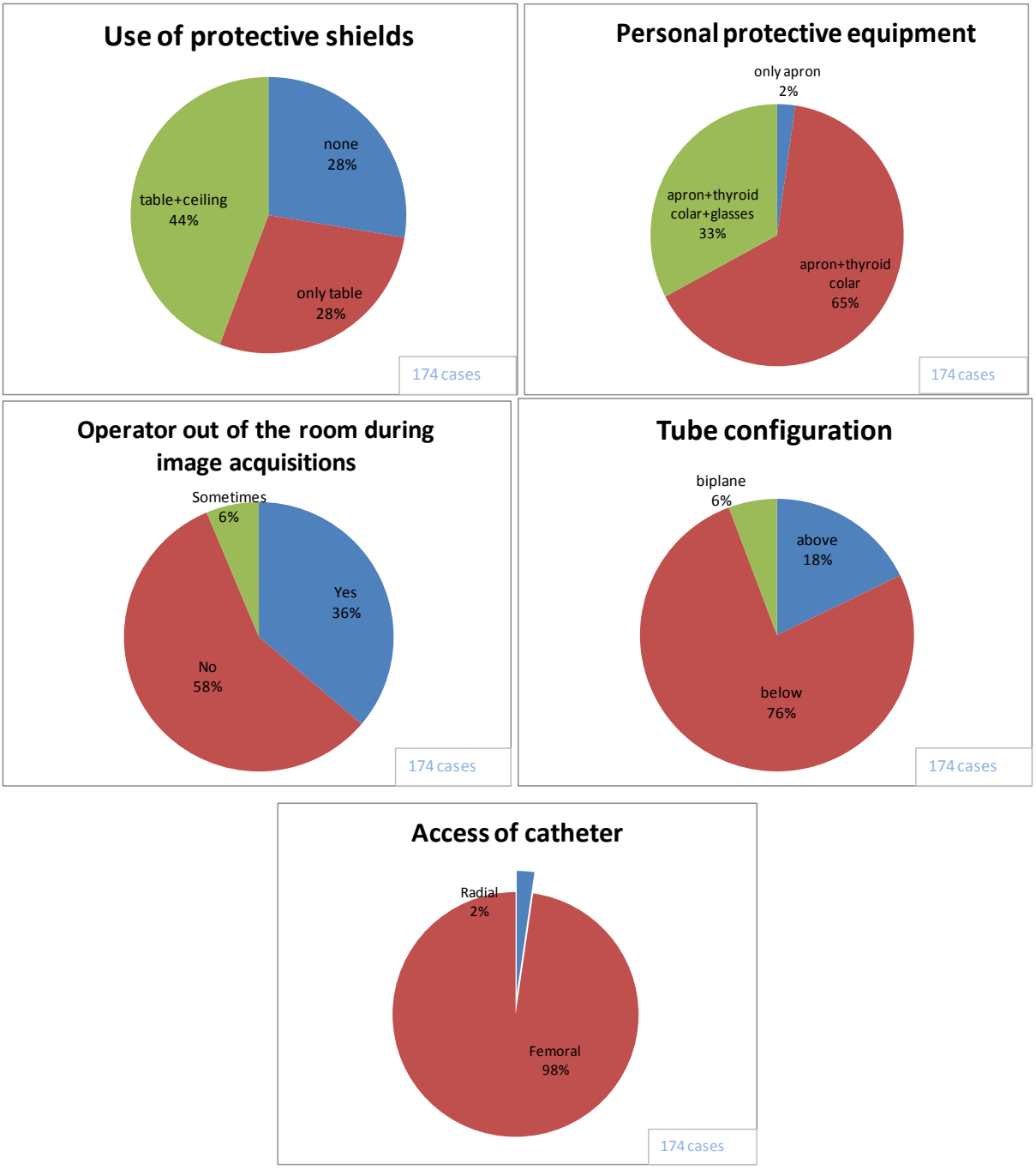
Graph 64: Median KAP values at the various hospitals where the measurement campaign for the embolization procedures took place

A1, A5, C2, C5 and E2b (only 5 cases) hospitals performed only chemo-embolisation procedures; B8, D2, E1 and E5b performed mostly neuro-embolisations; E2a and E5a only performed embolisations of the spermatic or ovarian veins and the KAP values are very low; the rest of the hospitals perform various types of embolisation. Hospitals B3, B7 and D3 perform chemo-, neuro- and renal embolisations and present relatively high KAP values. In hospital E4 embolisations of the abdominal area, the pelvis and the liver are performed but the KAP values were relatively low. However, the doses that were recorded for the operators at this hospital were significantly higher than others mainly because they use fluoroscopic system with overcouch irradiation and neither ceiling suspended shield nor table shield are available in this room. Operators at hospital E5a also present high doses/KAP for the same reasons.



Graph 65: Median H_p/KAP values at the various hospitals where the measurement campaign for the embolization procedures took place.

In the next graphs some statistics are presented giving information on the use of the room protective equipment, access of the catheter, tube configuration and going outside the room or staying inside during the image acquisitions.

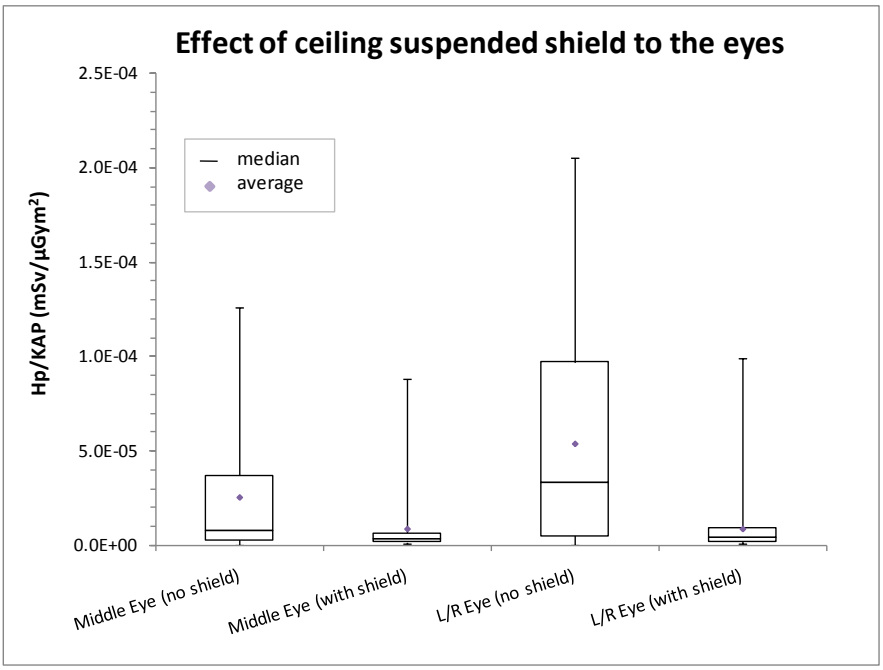


Graph 66: Statistics with the use of the room and personal protective equipment, tube configuration, access, and going outside the room or not during the image acquisitions

Only in 44% of the cases both table and ceiling suspended shields were used. A lead apron and thyroid collar were almost always used, however, only 33% of the operators wore protective glasses. Moreover, the operators left the room during image acquisitions in more than half the cases. Undercouch irradiation was used most of the times and biplane technique was sometimes used especially in neuro-embolisation procedures. Finally femoral access was used in almost all the procedures.

2.5.2 Effect of room protective equipment, tube configuration and the in/out during cine mode parameter

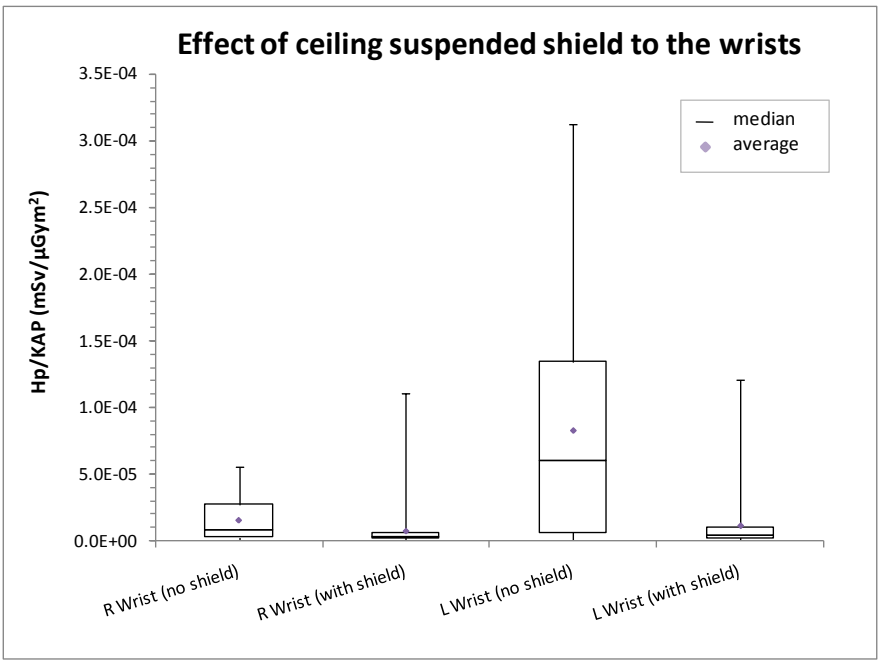
The use of ceiling suspended shield was studied for the effect on the reduction on the eye, finger and wrist doses. The results are presented in the following graphs. The reduction ratio is also calculated. Only the cases where the operator stays inside the room during image acquisitions are included in order to have a clear view on the effect of the shields.



with ceiling shield: 49 cases
without ceiling shield : 51 cases

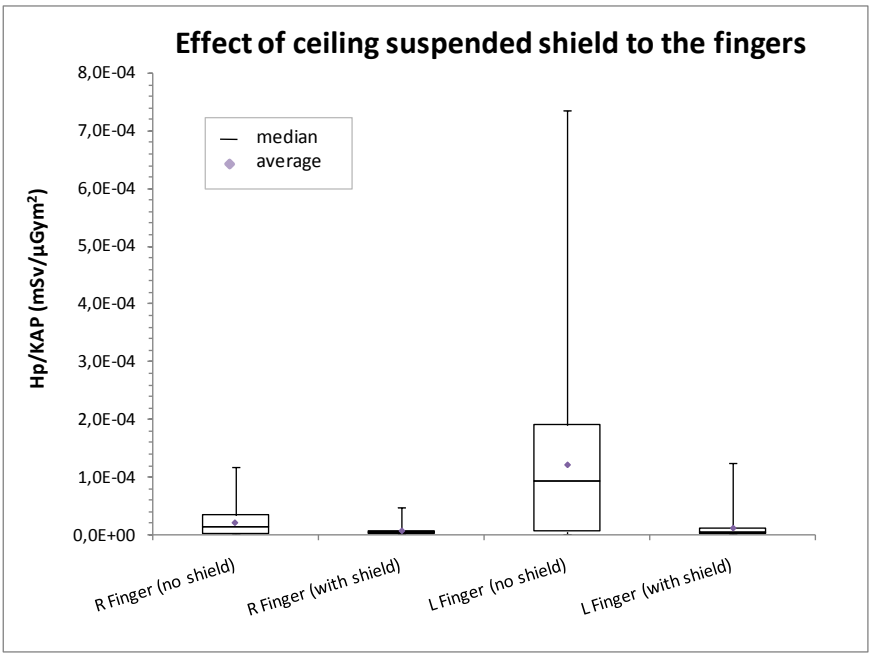
% reduction		
M eye	L eye	
60%	86%	**median**
Ratio (without/with)		
2.52	7.4	median

Graph 67: The effect of the ceiling suspended shield to the eye doses



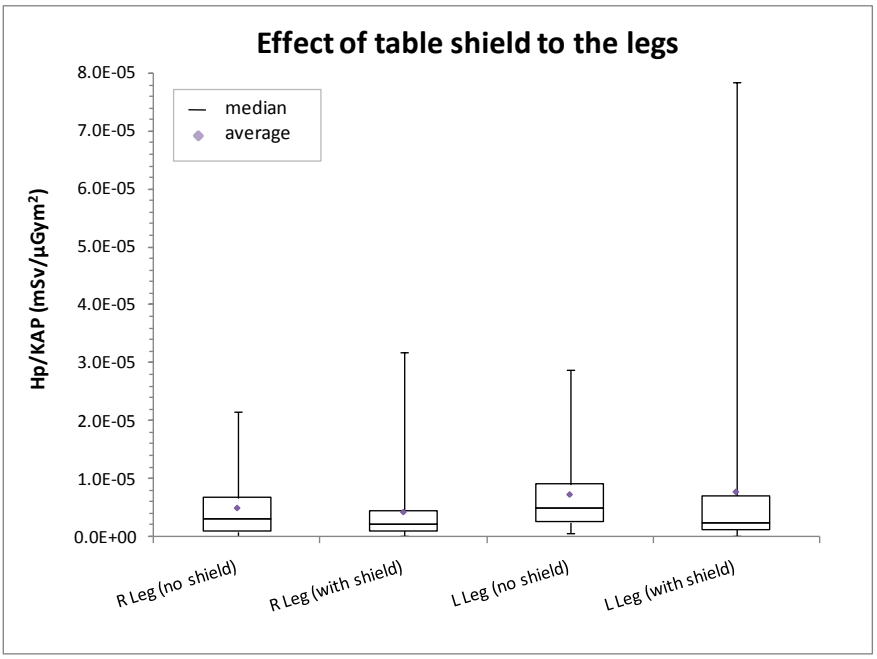
% reduction		
R wrist	L wrist	
60%	92%	**median**
Ratio (without/with)		
2.49	12.94	median

Graph 68: The effect of the ceiling suspended shield to the wrist doses



% reduction		
R finger	L finger	
74%	95%	**median**
Ratio (without/with)		
3.84	19.35	median

Graph 69: The effect of the ceiling suspended shield to the finger doses



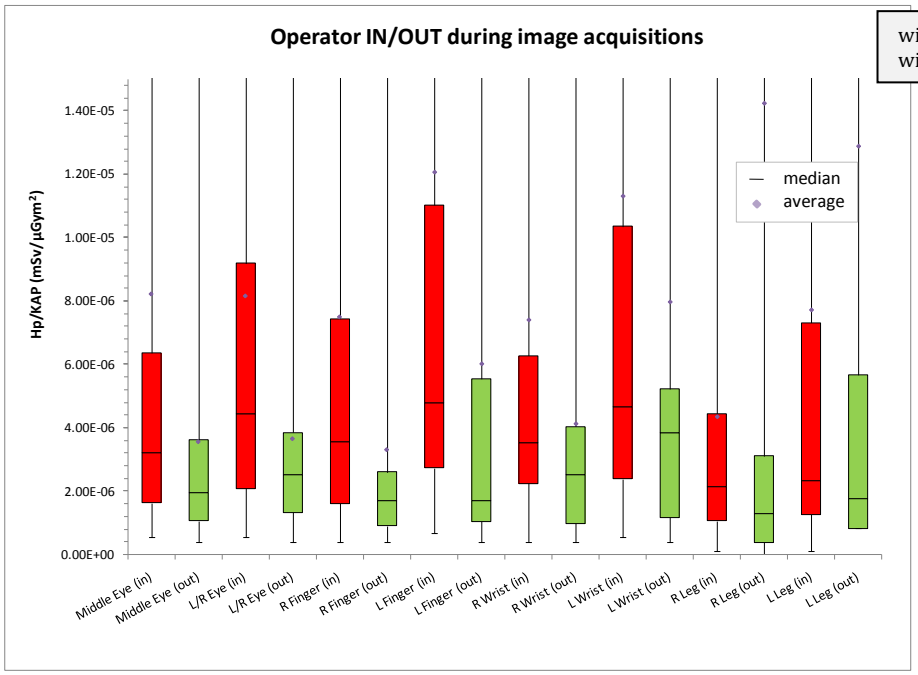
with table shield: 67 cases
without table shield : 33 cases

% reduction		
R leg	L leg	
32%	53%	**median**
Ratio (without/with)		
1.47	2.12	median

Graph 70: The effect of the ceiling suspended shield to the leg doses

As it is shown from the above graphs the use of ceiling shield reduces the dose to the eyes 60 to 86%, the dose to the fingers by 74-95 % and 60-90% to the wrists. The use of table shield reduces the dose to the legs by 30-50%.

The effect of the parameter "staying inside the room or going outside during the cine mode" is studied in the following graph. Only the cases where shields were present and tube was below the table are considered because the sample was bigger.



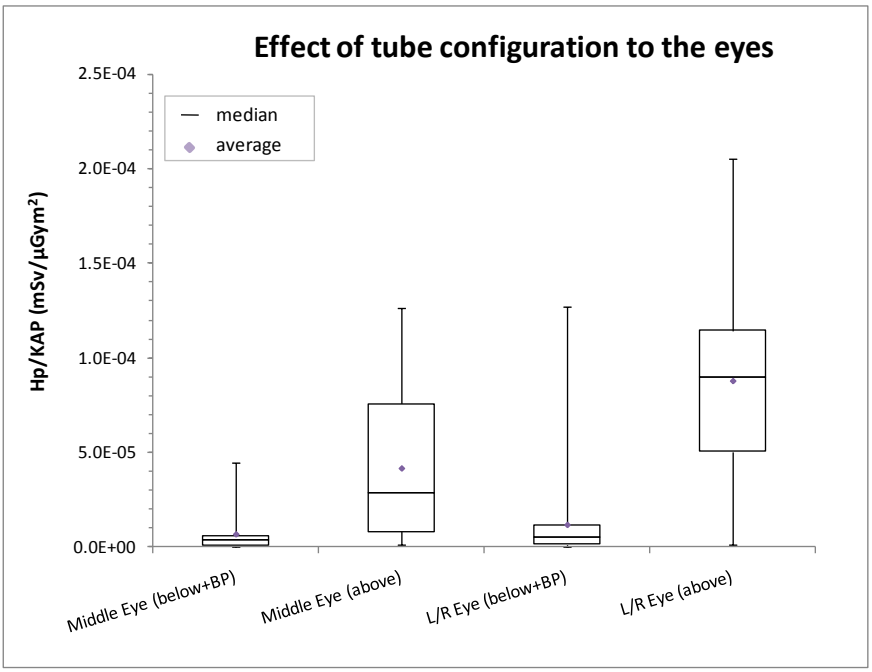
with table shield: IN 66 cases, OUT 58 cases
with ceiling shield:IN 49 cases, OUT 27cases

% reduction from out							
M eye	L eye	R finger	L finger	R wrist	L wrist	R leg	L leg
39%	44%	52%	64%	29%	18%	39%	24%
ratio (IN/OUT)							
1.64	1.77	2.07	2.80	1.40	1.22	1.64	1.31

Graph 71: The H_p/KAP doses for the personnel going out or staying inside during the image acquisition mode (zoom graph). Ceiling and table shield are present. The tube is below the table.

The H_p/KAP values in all positions are higher when the operator stays inside the room during image acquisitions. The dose reduction when the operator goes outside from the room during acquisitions is more significant to the hands because the operator uses an automatic contrast injection system. The dose reduction for the various dosimetric positions varies from 18% (left wrist) to 65% (left finger).

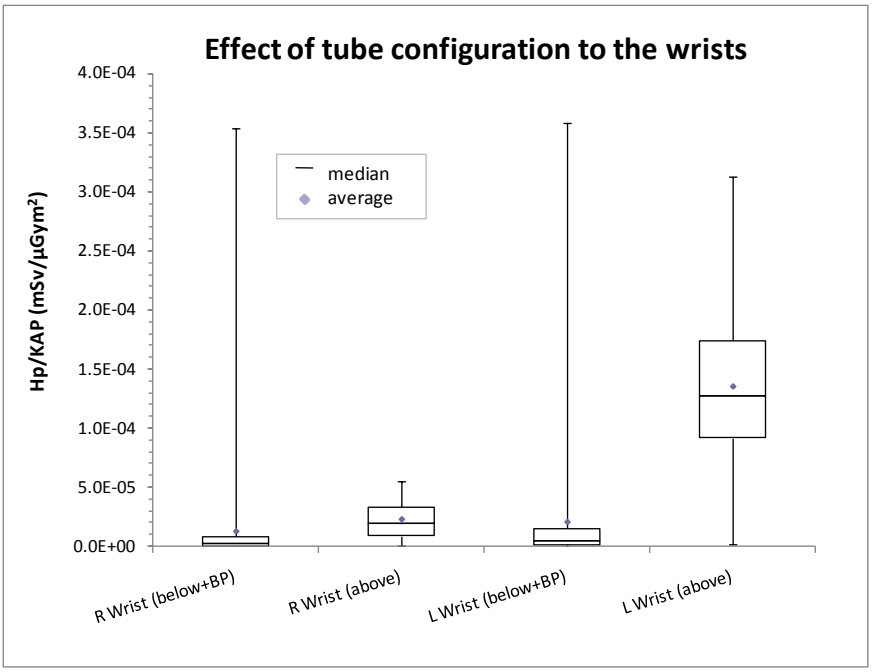
The effect of the tube configuration was studied for its effect on the eye, wrist finger and leg doses in the following graphs.



Above: 30 cases
Below: 67 cases

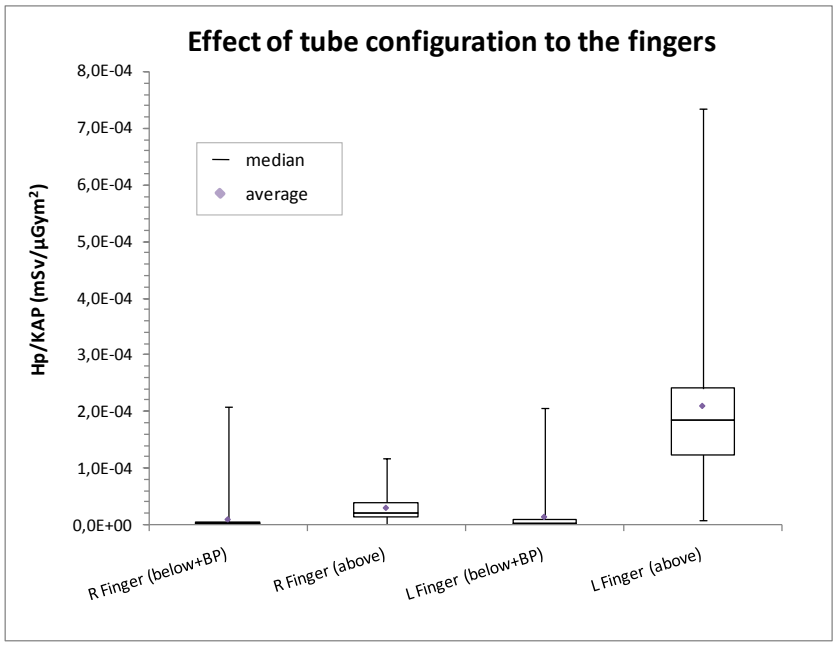
% (above-below/above)		
M Eye	L Eye	
88%	94%	**median**
Ratio (above/below)		
8.06	17.29	median

Graph 72: Effect of tube configuration to the eye doses when no protective ceiling suspended shield is used



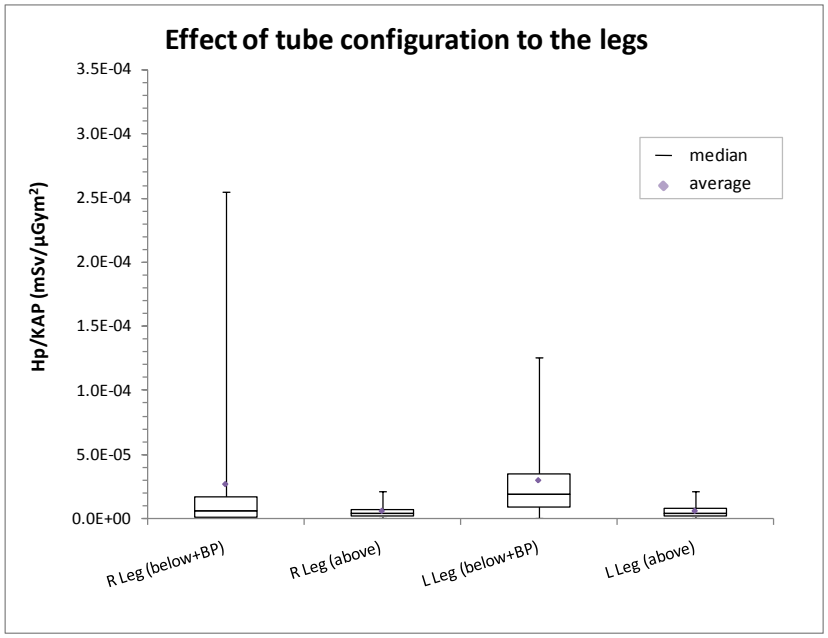
% (above-below/above)		
R Wrist	L Wrist	
85%	96%	**median**
RATIO above/below		
6.81	27.99	median

Graph 73: Effect of tube configuration to the wrist doses when no protective ceiling suspended shield is used



% (above-below/above)		
R Finger	L Finger	
89%	98%	**median**
RATIO above/below		
9.23	48.97	median

Graph 74: Effect of tube configuration to the finger doses when no protective ceiling suspended shield is used



Below+BP: 19 without shield
Above: 29 without shield

% (above-below/above)		
R Leg	L Leg	
-46%	-330%	**median**
RATIO above/below		
0.68	0.23	median

Graph 75: Effect of tube configuration to the leg doses when no protective table shield is used

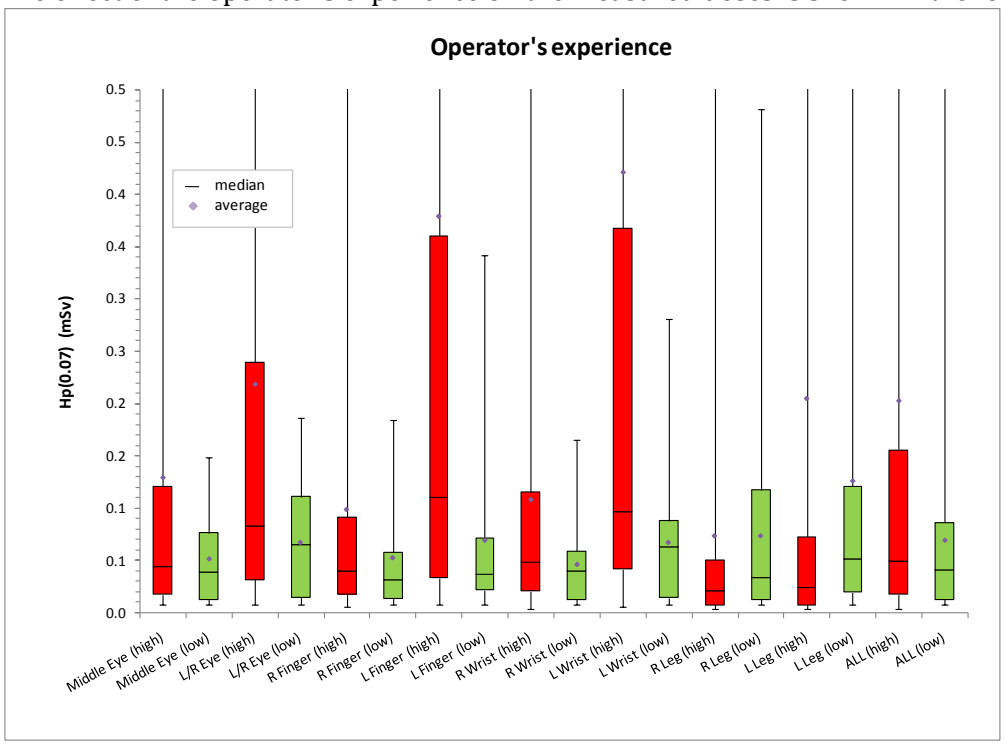
When the tube is located below the operating table or biplane technique is used, the dose to the eyes is 88 to 94% lower compared to the case where the tube is above the table. As far as the wrists and fingers are concerned the respective reduction is 85% (for the right wrist) and 98% (for the left finger).

For the legs, the doses were found higher 1.5 to 4.3 times (46-330%) when the tube was below. When no table shield is used the doses to the legs are higher when the tube is below the operating table. However, in the "tube above" cases, even if there was no table shield, the image intensifier was attached to the table and provided some kind of shielding to the legs. Care must be taken when a C-arm system is used incorrectly with the tube above the operating table and

there is no table shield In that case the legs of the operator would be much more exposed since the image intensifier is not attached to the table and does not provide protection.[1]

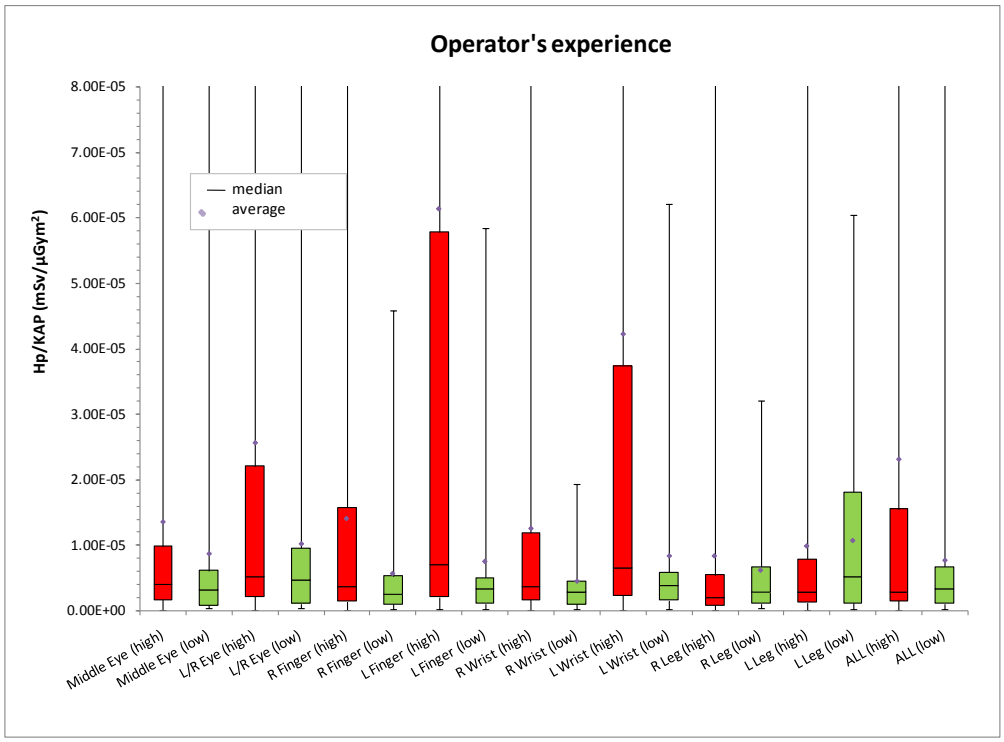
2.5.3 Experience

The effect of the operator's experience on the measured doses is shown in the following graphs.

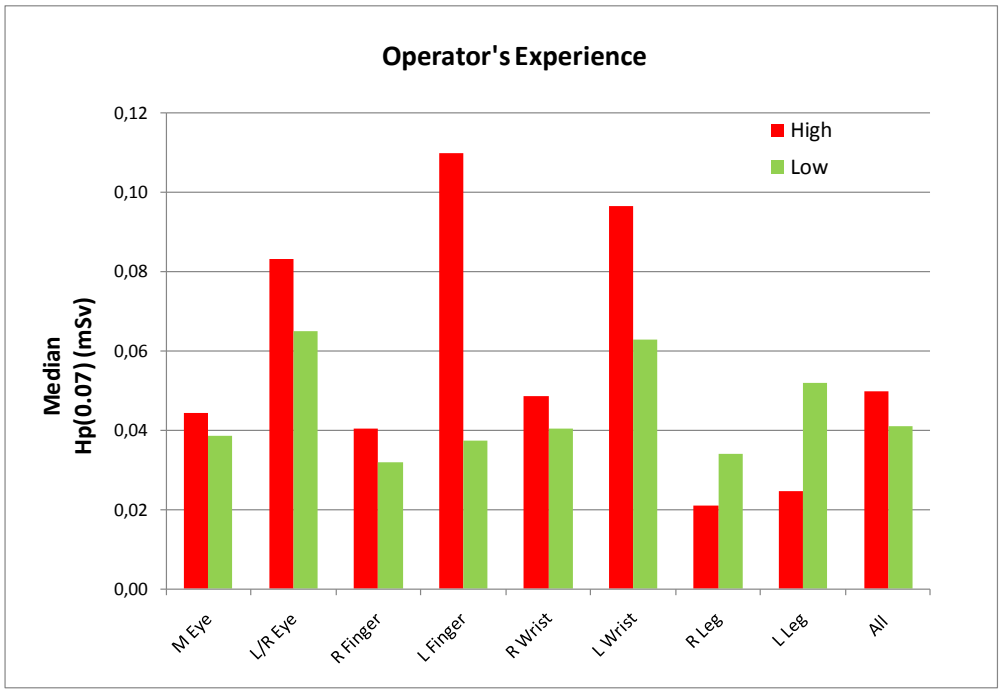


Graph 76: The effect of the operator's experience on the H_p values (ZOOM graph)

[1] The use of mobile C-Arm systems with the tube above the operating table has been observed during the measurements campaign. However, it is a bad practice example and it should be avoided.



Graph 77: The effect of the operator's experience on the H_p/KAP values (ZOOM graph)

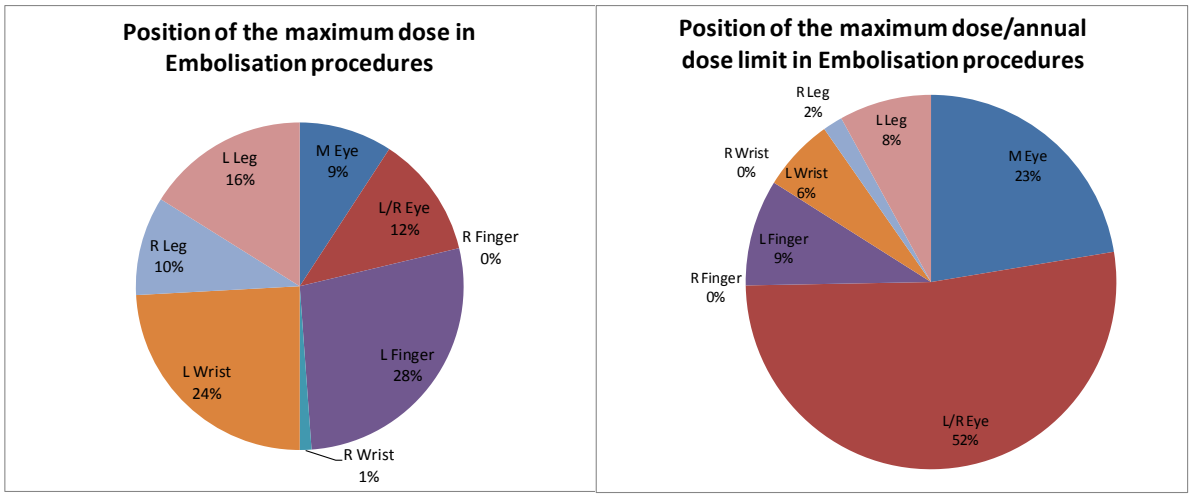


Graph 78: The median H_p values for high and low experienced operators

All positions, except for the legs, show higher dose values for the more experienced operators.

2.4.4 Position of the maximum

For the position of the maximum two pie charts are presented: one with the frequency of the position where the maximum dose was recorded and the other with the maximum dose recorded divided by the respective annual limits (150 mSv for the eyes and 500 mSv for the extremities).



Graph 79: Position of the maximum dose (on the left) and maximum dose divided by the respective annual limit (on the right)

The maximum dose was recorded most frequently on the left finger on the left wrist most of the times. However, taking into account the annual limits for all positions the most important is the exposure to the eye lens (52%).

2.5.5 Maximum doses

The following table presents the maximum doses and the respective conditions during which these doses were measured.

Table 4: The table presents the maximum doses in each dosimetric position and the condition during which these doses were measured

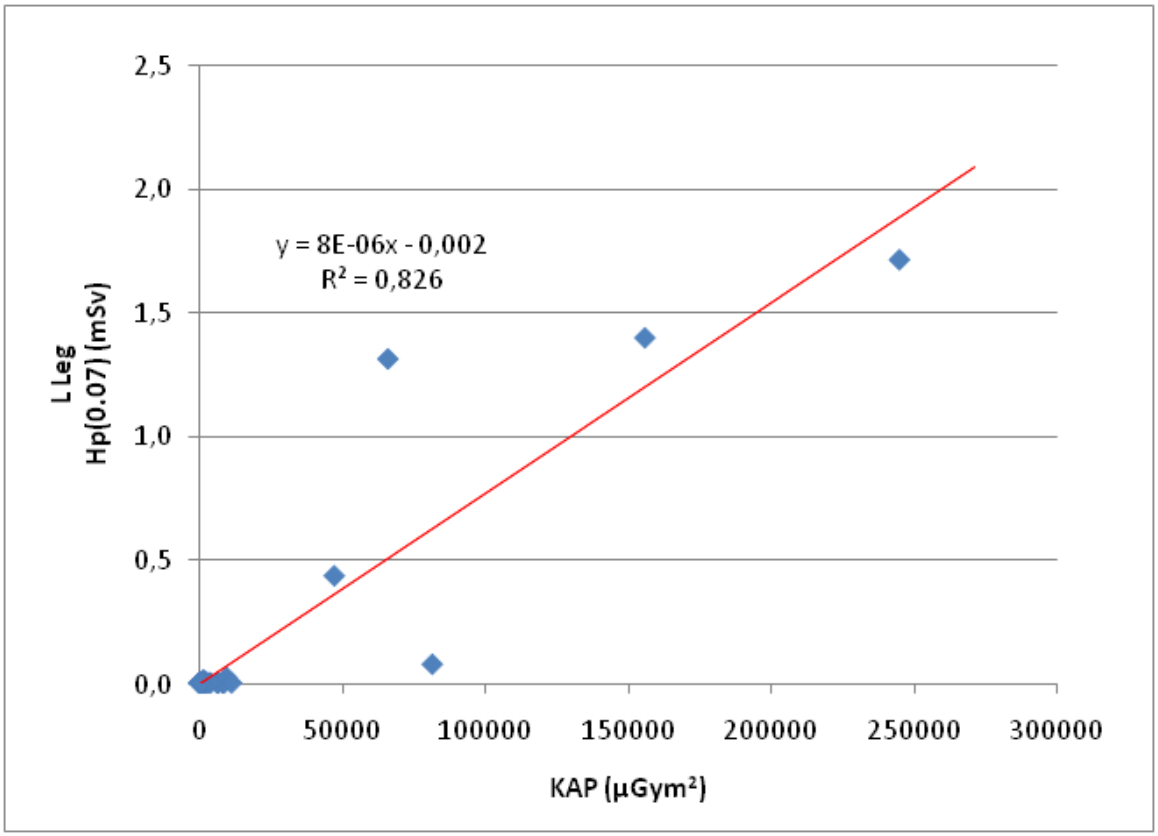
	L Finger	R Finger	L Wrist	R Wrist	L Leg	R Leg	L/R Eye	Middle Eye
Maximum Dose (mSv)	**7.32**	**0.91**	**9.51**	**0.78**	**7.82**	**1.74**	**2.44**	**1.22**
Protective equipment	none	none	table	table+ceiling	none	none	table+ceiling	
Out during image acquisitions	no	no	no	no	no	yes	no	
Tube configuration	above	below	below	below	below	below	biplane	
KAP (µGym²)	9970	270995	74520	53844	270995	18991	204850	
Procedure	Abdominal Embolisation	Liver chemo embolisation	Renal Embolisation	Liver chemo embolisation	Liver chemo embolisation	Liver chemo embolisation	Brain aneurysm	
Comments		Hands very close to beam - Complicated procedure	Left hand and arm in beam - Complicated procedure		Hands very close to beam - Complicated procedure		Complicated procedure - Ceiling shield only covered one tube	

From the table it is evident that the maximum values are measured for bad practice working conditions: no protective equipment, not going outside during cine, high KAP values and when the hands are very close to the primary field.

2.5.6 Correlations

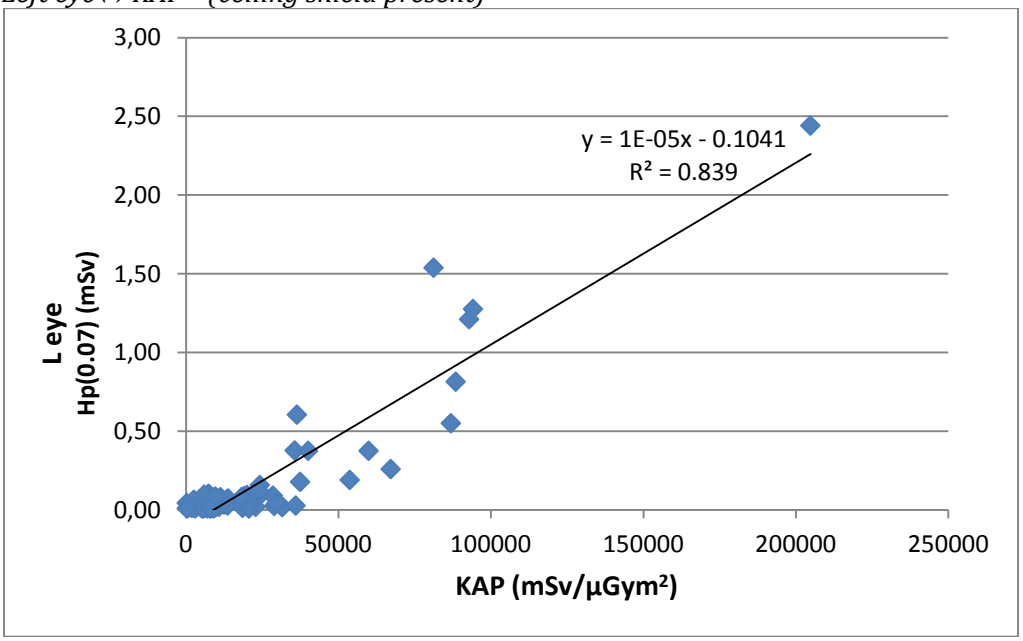
The parameters that were found to be correlated are:

- *Left leg↔KAP (staying inside the room for cine mode, no table shield)*



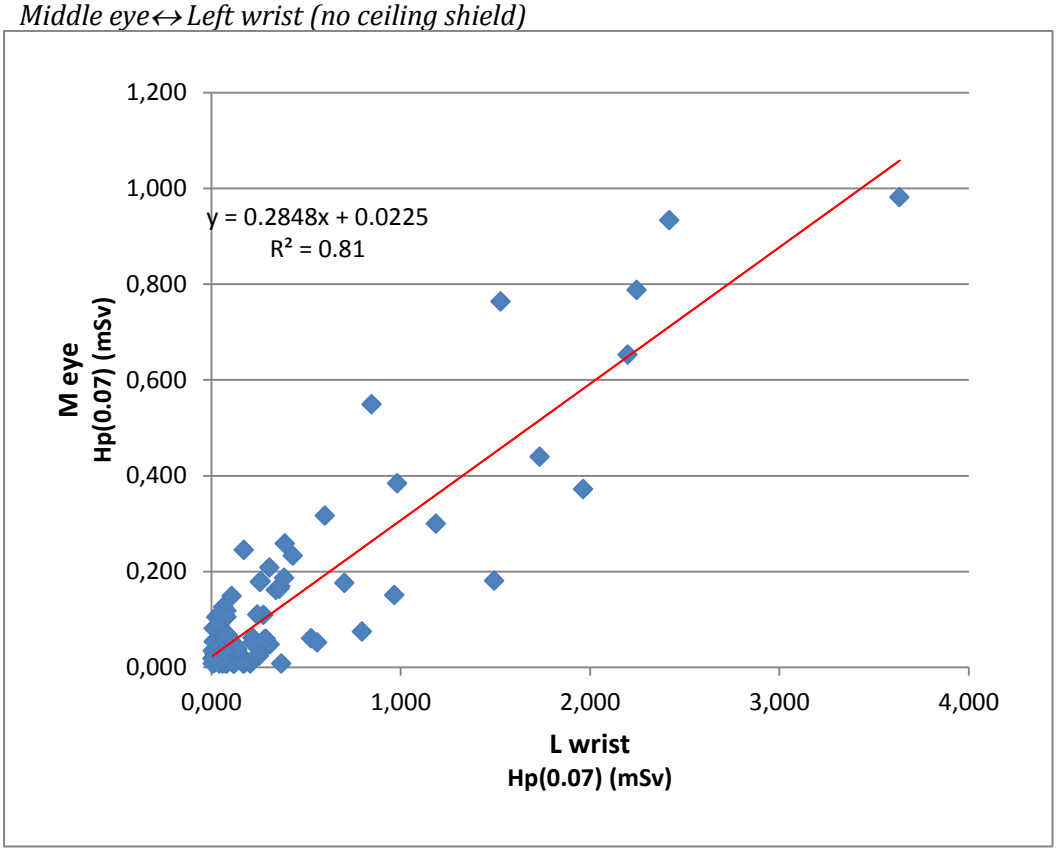
Graph 80: Correlation between the Left Leg and the respective KAP values when there is no table shield and the operator stays inside the room

- *Left eye↔KAP (ceiling shield present)*



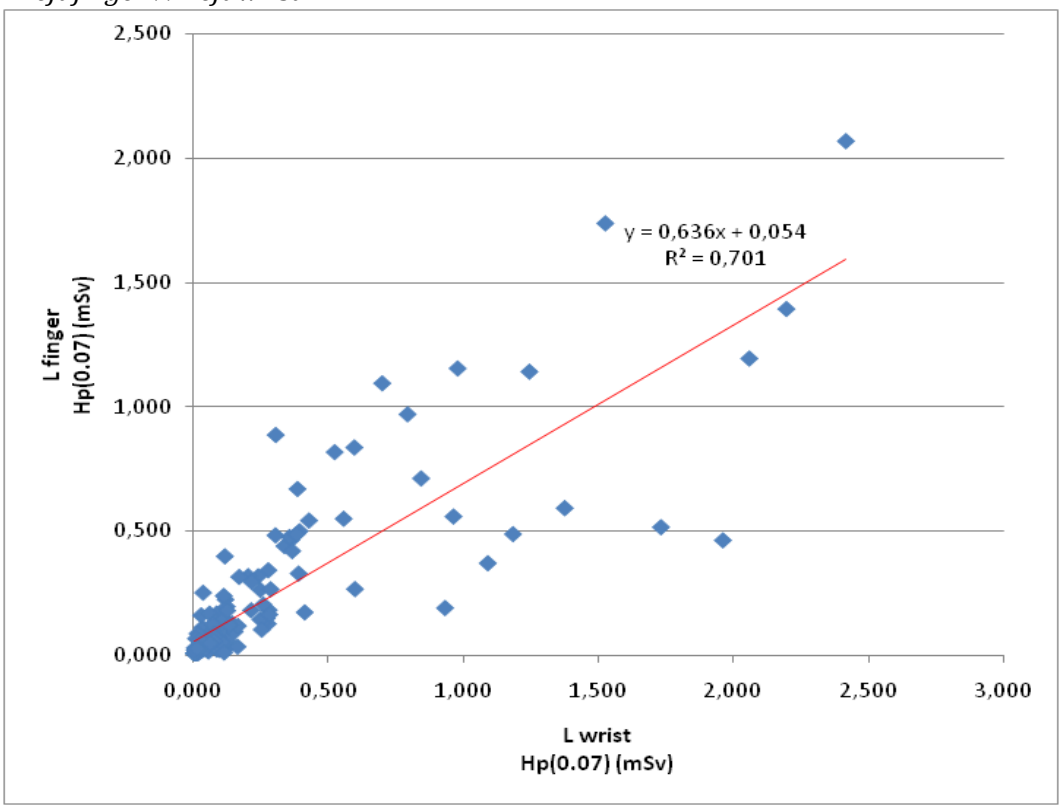
Graph 81: Correlation between the Left Eye and KAP values when the ceiling suspended shield is present

- *Middle eye↔Left wrist (no ceiling shield)*



Graph 82: Correlation between the Middle Eye and Left wrist values when no ceiling shield is used

- *Left finger↔Left wrist*



Graph 83 Correlation between the Left Finger and Left wrist values

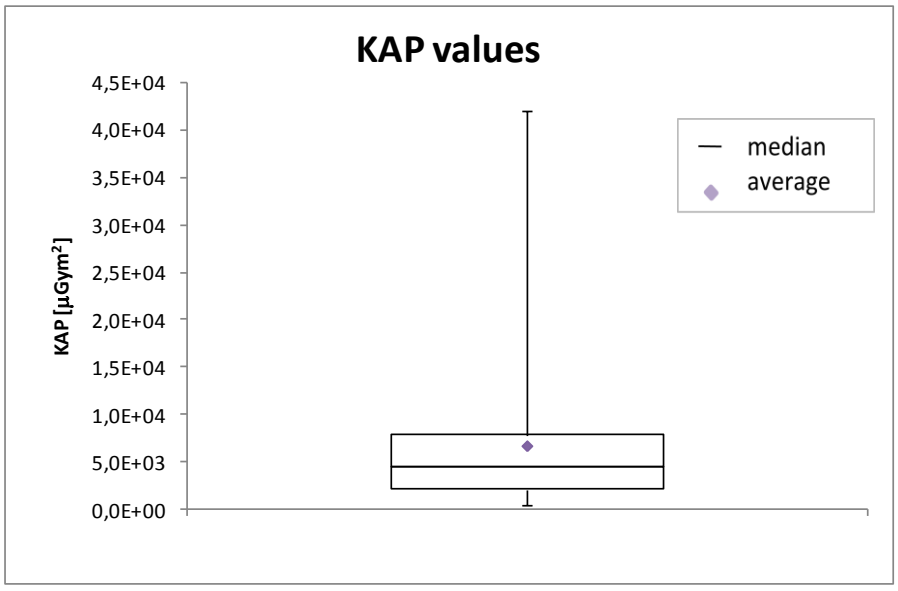
2.5.7 Conclusions

- There is a statistically significant influence of the ceiling suspended shield on the eye, fingers and wrist doses. The respective reduction ratios are: 2.5 to 7 times for the eyes, 4-19 times for the fingers and 2.5 to 13 times for the wrists
- There is also a statistically significant influence of the table shield on leg doses (1.5 to 2 times)
- Moreover, there is a statistically significant influence of the parameter going outside the room or staying inside during the cine mode on the dose results for all dosimetric positions. The highest reduction was recorded for the left finger (2.8 times)
- The tube configuration clearly influences the doses. There is an increase at the eye (8 to18 times), wrist (7 to 28 times) and finger (9 to 49 times) doses when the tube is above and an increase at the leg doses when the tube is below the table
- All positions except for the legs show higher H_p/KAP values for the more experienced operators
- The maximum dose was recorded on the left finger and then on the left wrist most of the times. However, taking into account the annual limits for all positions special attention should be given to the eye lens
- The left finger and left wrist doses are well correlated. In the other cases the same protective measures should be taken into account in order to have good correlation. Generally when no protective equipment is used there is a correlation of the left and middle eye with the left wrist

2.6 Cardiac angiographies (CA) and angioplasties (PTCA)

2.6.1 General information

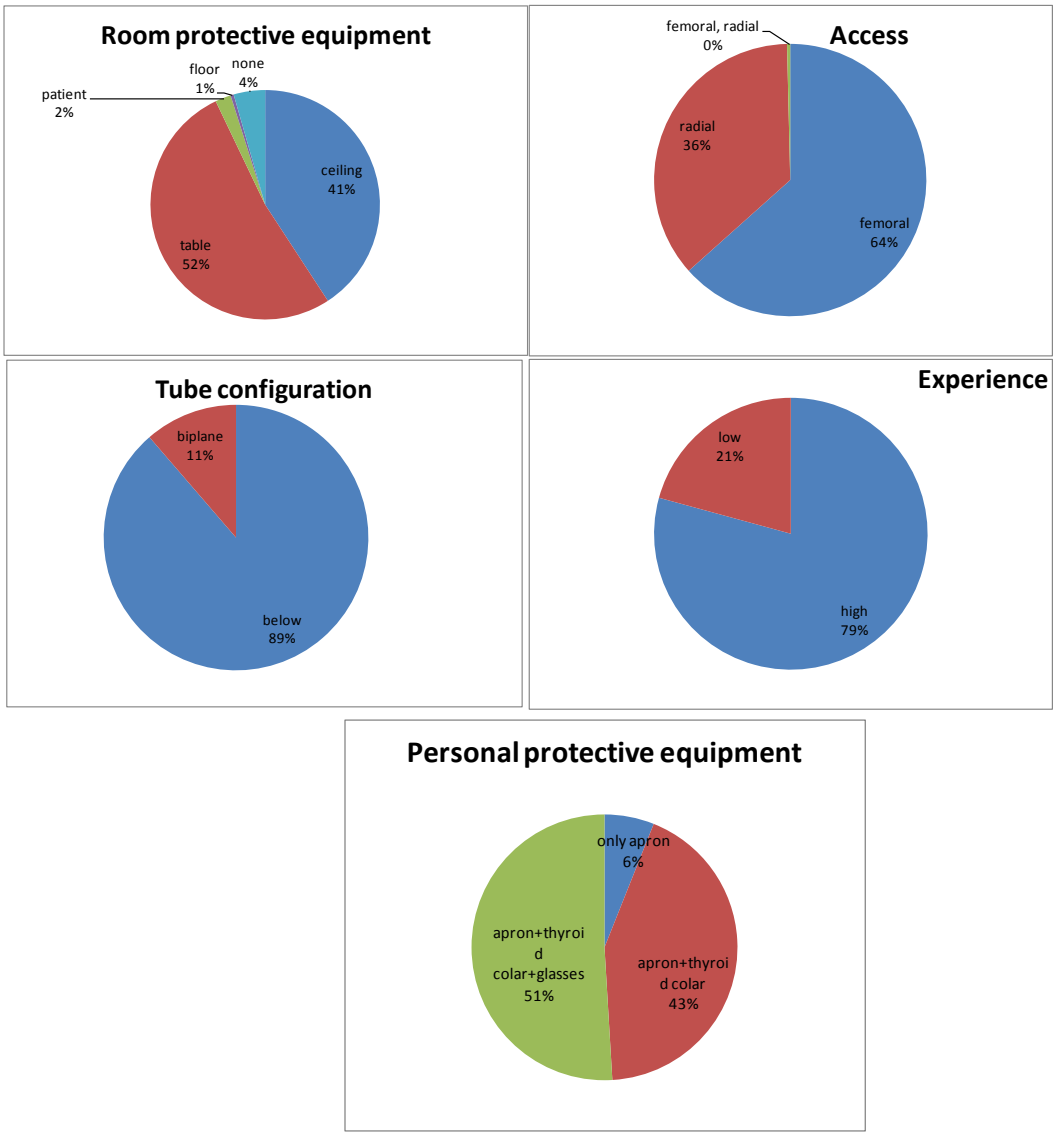
In total, 265 procedures were monitored in 22 hospitals. The following graph presents a box plot from the KAP values monitored for this procedure in all hospitals and the next one, the median KAP values for each hospital.



Graph 84: Box plot with the KAP values for all the monitored CA and PTCA procedures

The various H_p/KAP values measured for the CA and PTCA procedures in each hospital are presented in Appendix 1.

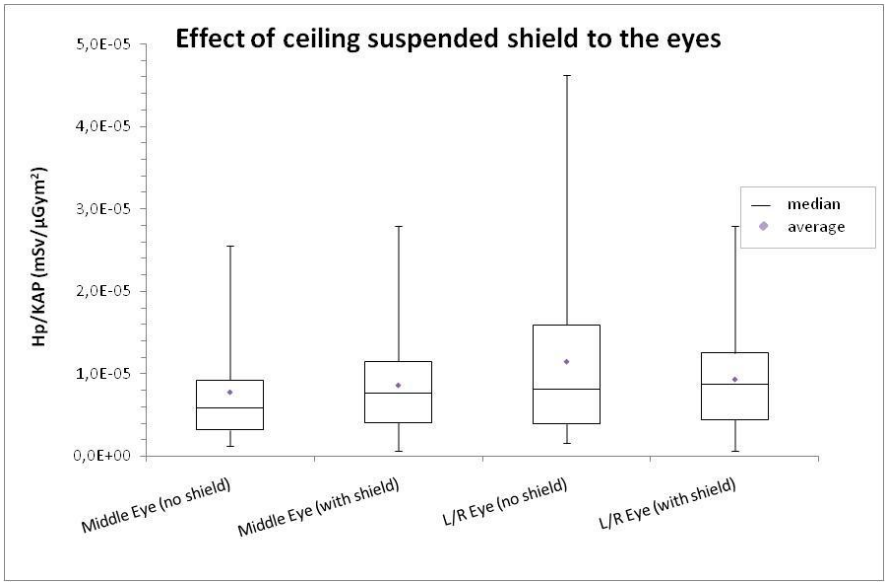
In the next graphs some statistics are presented giving information on the use of the room and personal protective equipment, tube configuration, access of the catheter and experience of the operator.



Graph 85: Statistics with the use of the room and personal protective equipment, tube configuration, access, and experience of the operator

2.6.2 Effect of room protective equipment, tube configuration and access

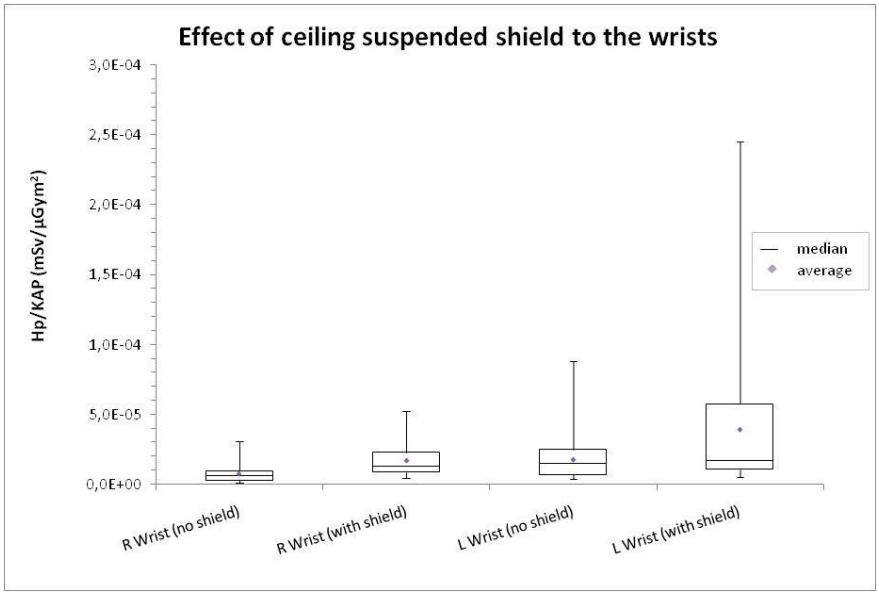
The use of ceiling suspended shield was studied for the effect on the reduction of the eye, finger and wrist doses. Two accesses for cardiac catheterization, femoral and radial, were encountered during the analyses. The analysis of the influence of protective equipment on the doses is performed for these two kinds of access; only cases with tube below are taken into account in the following graphs. The reduction ratio is also calculated using the median values.



with ceiling shield: 97 cases
without ceiling shield : 43 cases

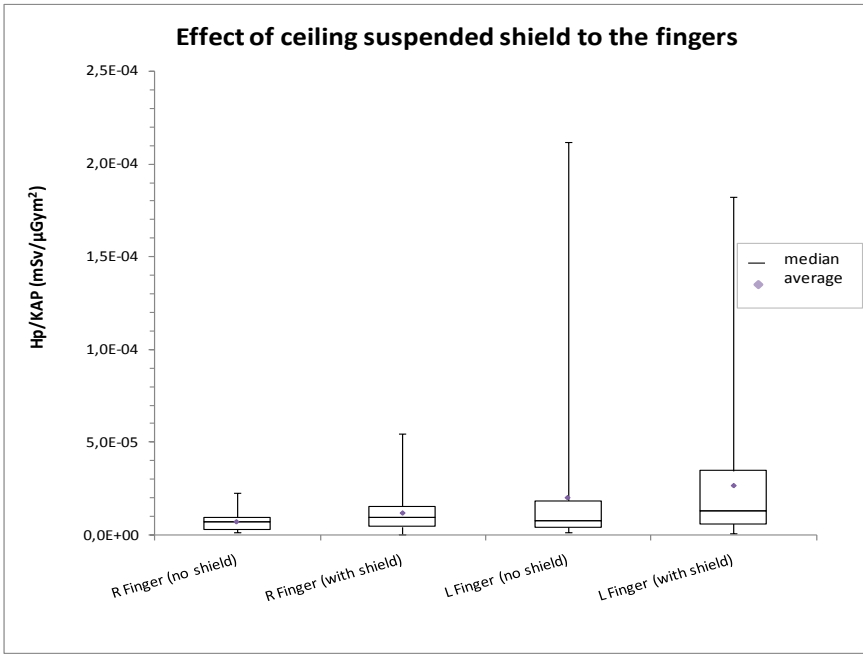
Left eye	Middle eye	
without/with		
0.9	0.8	for median
Reduction [%]		
-7.8	-32.7	for median

Graph 86: The effect of the ceiling suspended shield to the eye doses for femoral access and tube below configuration



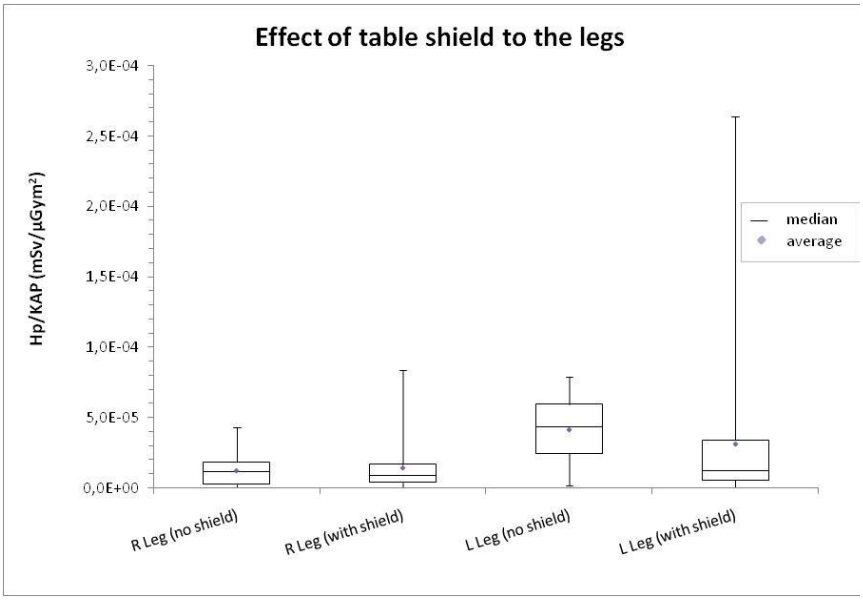
Left Wrist	Right Wrist	
without/with		
0.9	0.5	for median
Reduction [%]		
-14.8	-94.3	for median

Graph 87: The effect of the ceiling suspended shield to the wrist doses for femoral access and tube below configuration



Left Finger	Right Finger	
without/with		
0.6	0.8	for median
Reduction [%]		
-64.5	-31.6	for median

Graph 88: The effect of the ceiling suspended shield to the finger doses for femoral access and tube below configuration



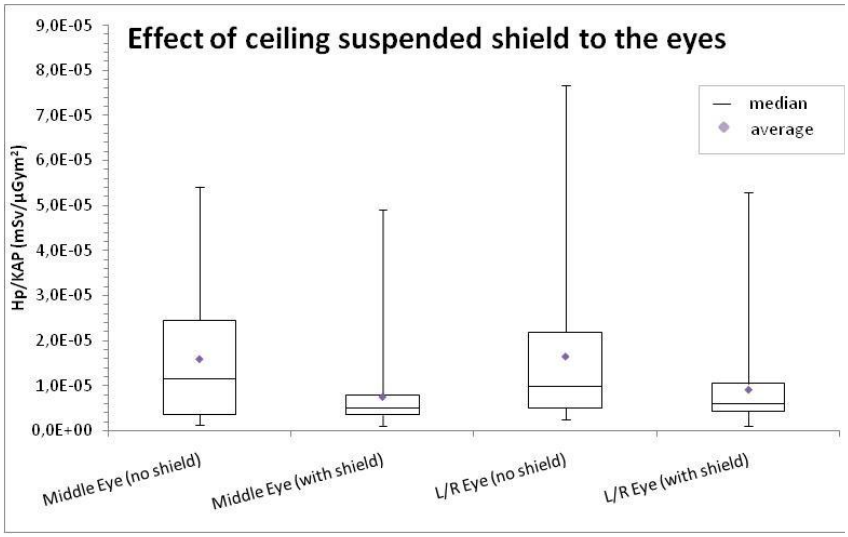
with table shield: 112 cases
without table shield : 28 cases

Left Leg	Right Leg	
without/with		
3.5	1.3	for median
Reduction [%]		
71.5	25.5	for median

Graph 89: The effect of the table shield to the leg doses for femoral access and tube below configuration

The effect of protective equipment with femoral access of the catheter is observed *only* for the legs; the dose reduction is about 72%. In case of the eyes the ratio 'without/with' is close to one for the left eye (0.9) and 0.8 in the region between eyes. For the hands the median doses are higher when a ceiling is present (for the left wrist the ratio 'without/with' is 0.9 while for the left finger it is 0.6)

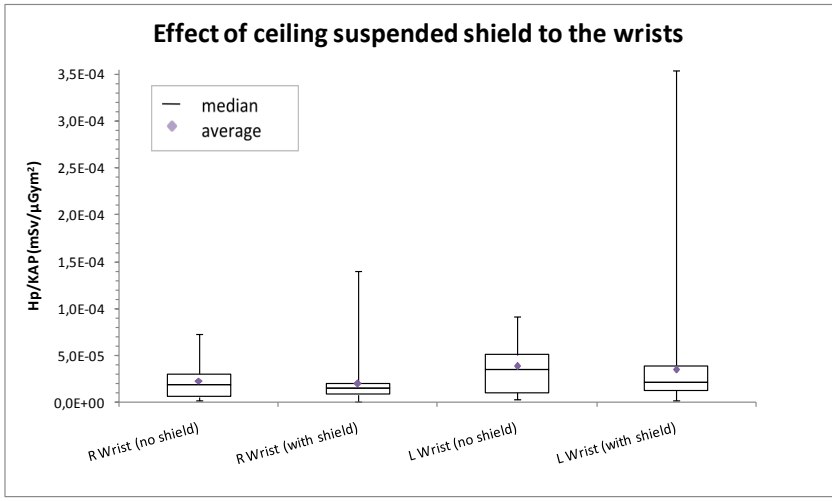
For the radial access the similar analysis has been performed, but not for the table since there is only one case without table shield and radial access.



with ceiling shield: 66 cases
without ceiling shield : 27 cases

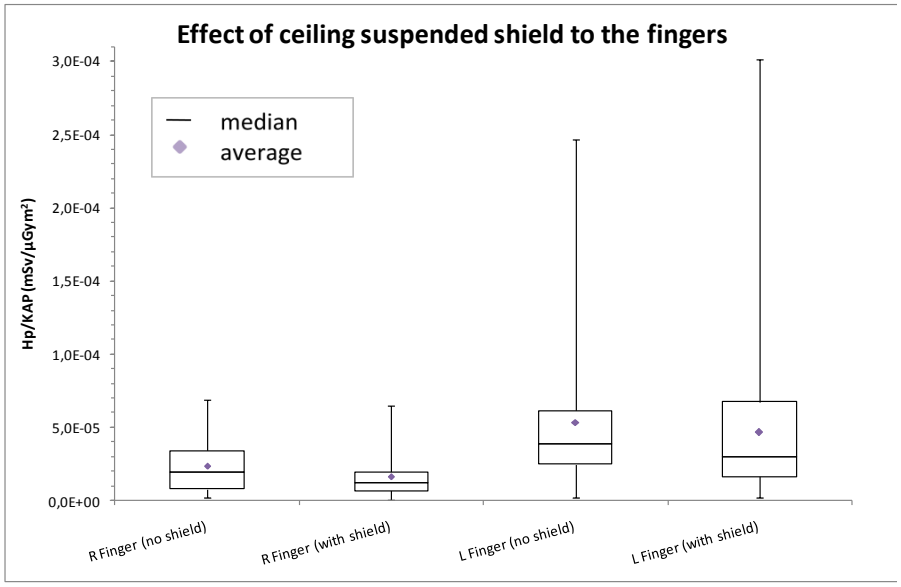
Left Eye	Middle Eye	
without/with		
1.6	2.3	for median
Reduction [%]		
38.1	56.8	for median

Graph 90: The effect of the ceiling suspended shield to the eye doses for radial access and tube below configuration



Left Wrist	Right Wrist	
without/with		
1.7	1.3	for median
Reduction [%]		
39.6	22.2	for median

Graph 91: The effect of the ceiling suspended shield to the wrist doses for radial access and tube below configuration

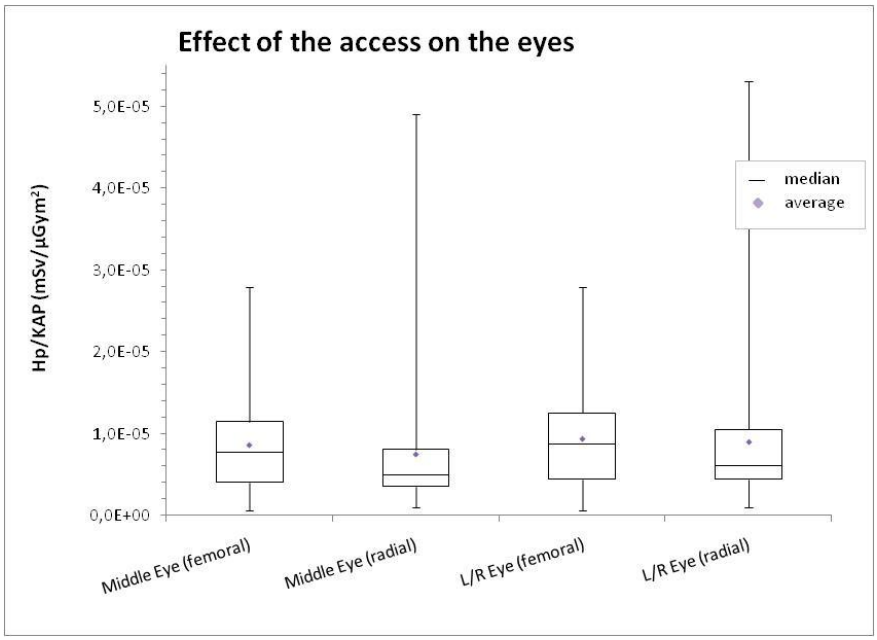


Left Finger	Right Finger	
without/with		
1.3	1.6	for median
Reduction [%]		
23.3	36.0	for median

Graph 92: The effect of the ceiling suspended shield to the finger doses for radial access and tube below configuration

For the radial access the effect of the ceiling shield on the dose reduction is observed in all dosimeter positions. For the eyes, the doses are reduced by 38% on the left eye and 57% in the region between eyes when the ceiling shield is used. For the fingers the doses are reduced by 23% on the left finger and 36% on the right finger. The respective data for the wrist are 40% and 22%.

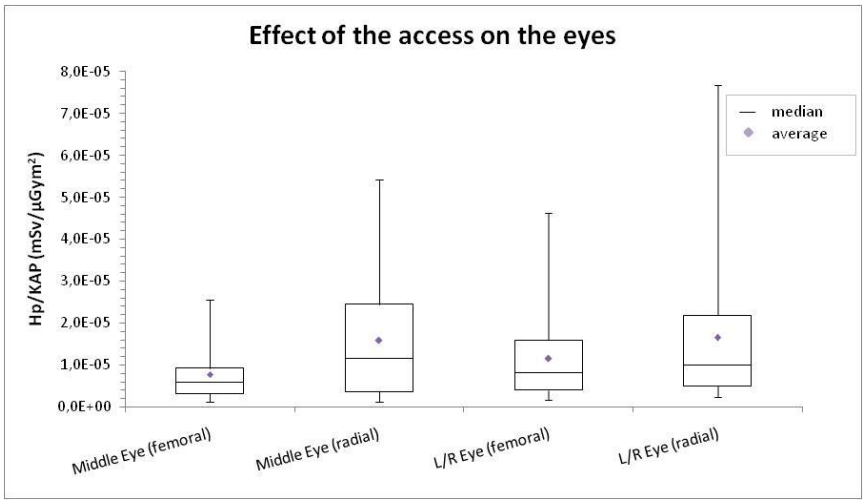
The influence of the access of the catheter on the doses is also investigated. In the following graphs the effect of catheter access on the eye dose is presented when ceiling suspended shield is present and when it is absent.



Femoral: 97 cases
Radial: 66 cases

Left Eye	Middle Eye	
radial/femoral		
0.7	0.6	for median

Graph 93: The effect of the access to the eye doses when the ceiling suspended shield is present and tube is below the table

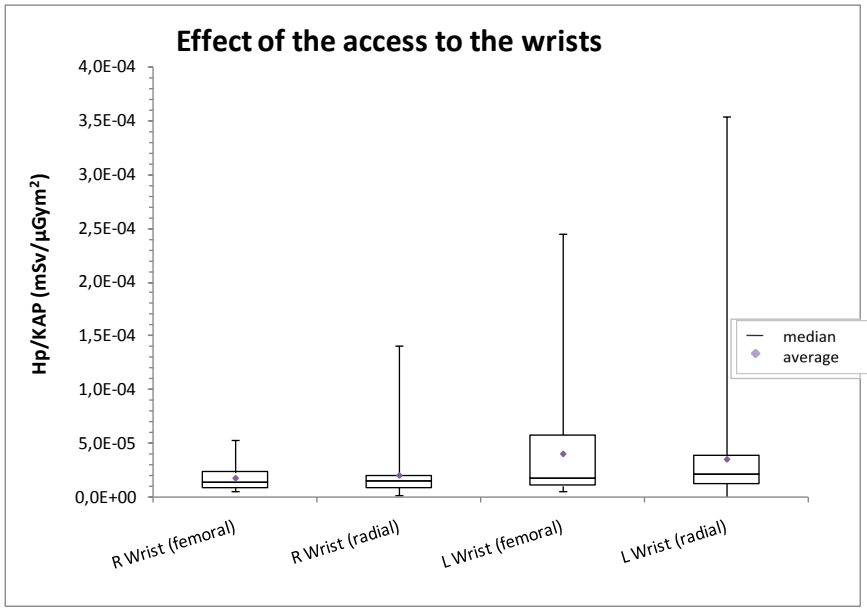


Left Eye	Middle Eye	
radial/femoral		
1.2	2.0	for median

Graph 94: The effect of the access to the eye doses when the ceiling suspended shield is absent and tube is below the table

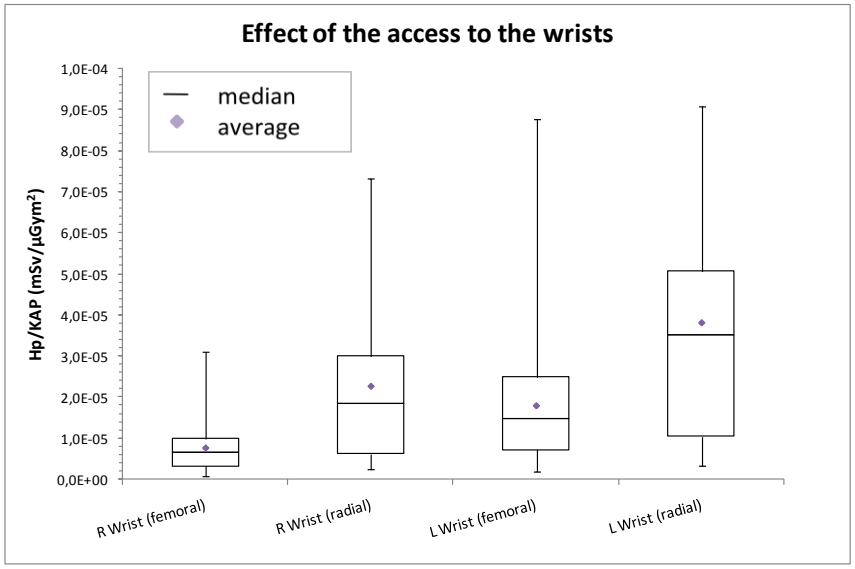
When no ceiling shield is used, it is clear that the higher doses to the eyes are obtained for the radial access as in this case the operator is closer to the X-ray beam, compared to femoral access. However, if a ceiling shield is used, the adverse effect is observed: femoral access gives higher doses than radial access. A possible explanation is that the ceiling shield is better positioned at radial access than at femoral access. When the operator is closer to the X-ray beam (radial access), it is easier to correctly use the shield.

In the following two graphs the effect of the catheter access on the wrist dose is presented when the ceiling shield is present and when it is absent. Similar graphs are obtained for the fingers.



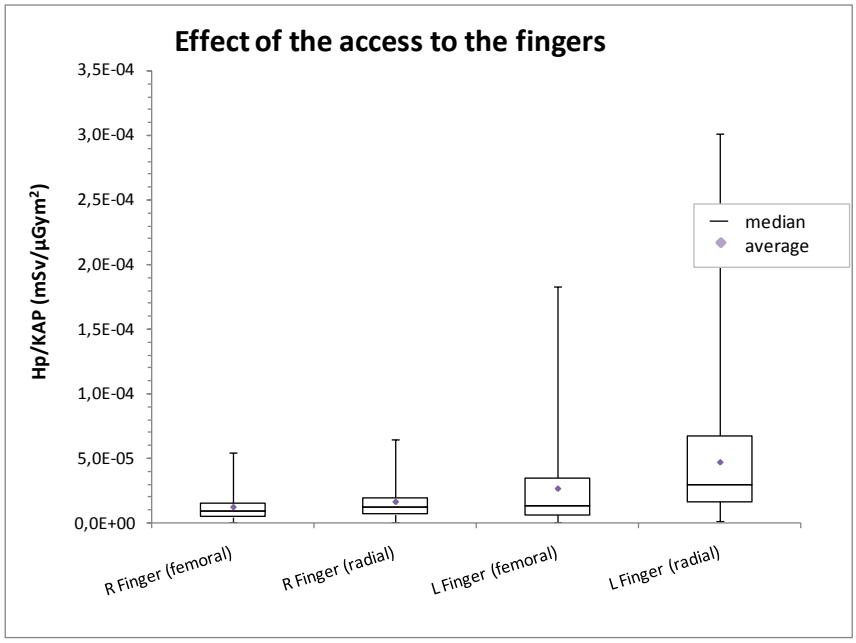
Left Wrist	Right Wrist	
radial/femoral		
1.3	1.1	for median

Graph 95: The effect of the access to the wrist doses when the ceiling suspended shield is present and tube is below the table



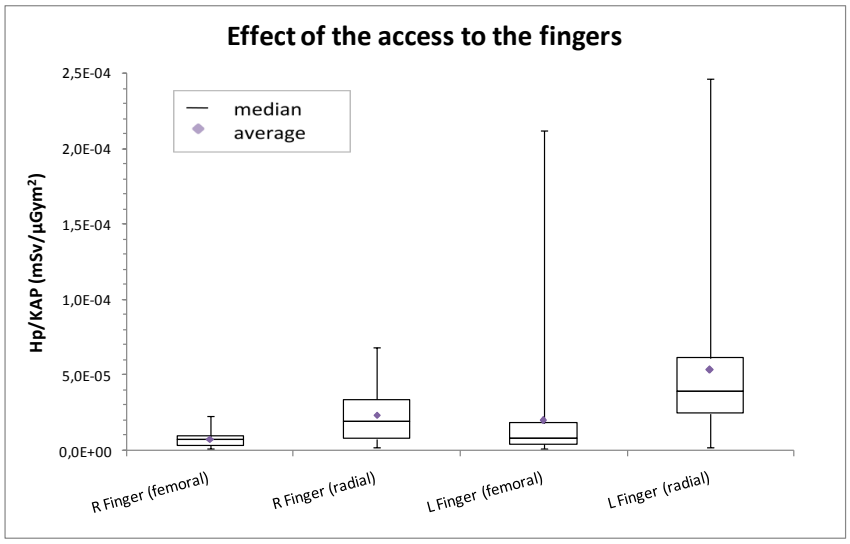
Left Wrist	Right Wrist	
radial/femoral		
2.4	2.8	for median

Graph 96: The effect of the access to the wrist doses when the ceiling suspended shield is absent and tube is below the table



Left Finger	Right Finger	
radial/femoral		
2.3	1.3	for median

Graph 97: The effect of the access to the finger doses when the ceiling suspended shield is present and tube is below the table

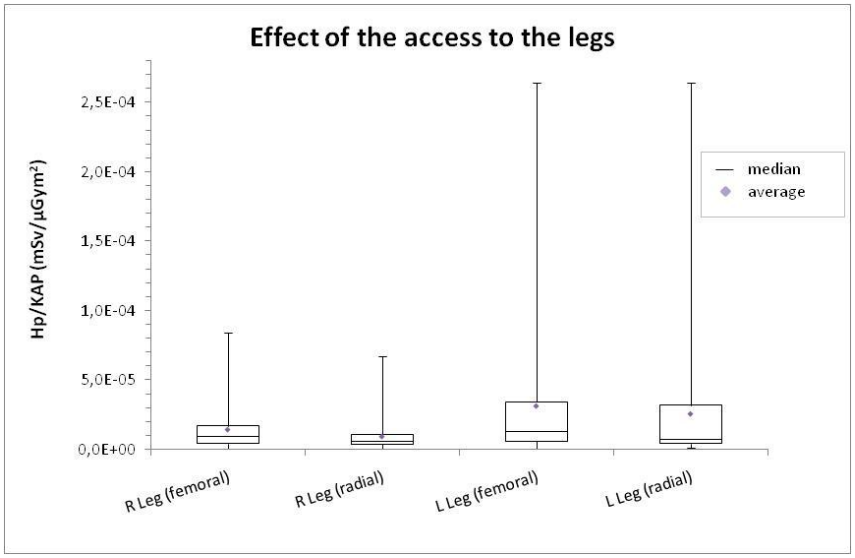


Left Finger	Right Finger	
radial/femoral		
4.8	2.6	for median

Graph 98: The effect of the access shield to the finger doses when the ceiling suspended shield is absent and tube is below the table

Similar conclusions can be formulated as for the eyes: a significant difference between radial access and femoral access is observed for the wrist and finger doses if no ceiling suspended shield is used (higher doses for radial access). If ceiling suspended shields are used, the differences in finger and wrist doses between radial and femoral access become smaller and less important.

In the following graph the effect of the catheter access is presented for the leg doses if table shield is present (not enough data available without table shield). Again, when shielding is used, femoral access results are higher or comparable doses to the legs compared to radial access.



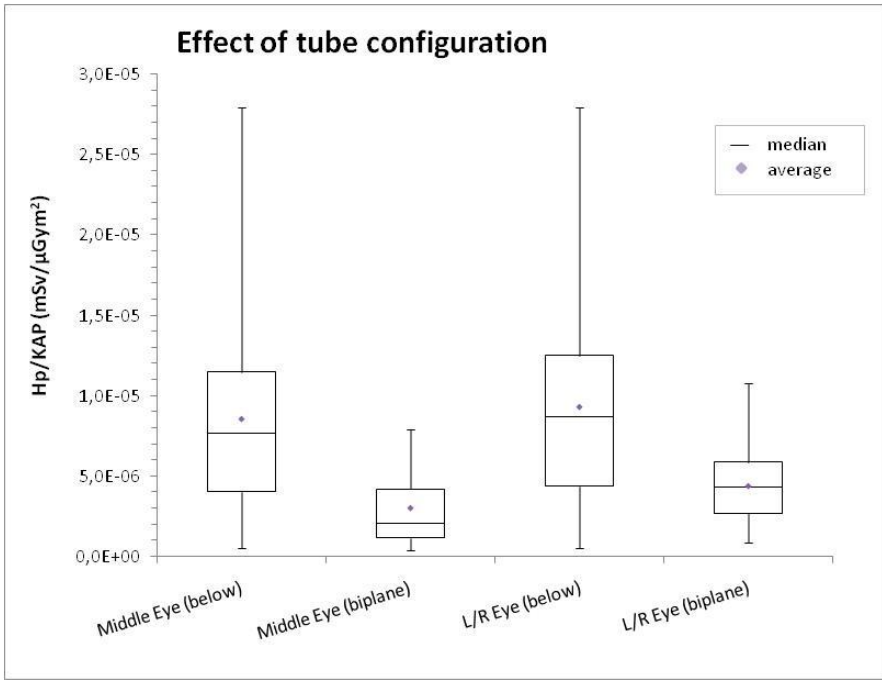
femoral: 112 without shield
radial: 92 without shield

Left Leg	Right Leg	
radial/femoral		
0.6	0.6	for median

Graph 99: The effect of the access to the leg doses when the table shield is present and tube is below the table

Generally the doses are expected to be higher for the radial access than for the femoral one since the operator is closer to the primary field and to the scattering material. Higher doses were found in the case of the hands (wrists and fingers). The differences are higher when the ceiling shield is not present. However, for the eyes, higher doses are observed for the femoral access and maybe this is due to the improper positioning of the ceiling shield. The same situation is observed for the legs where higher doses are measured when the femoral access is used. This is probably to the bad positioning of the table shield where it practically does not cover the legs.

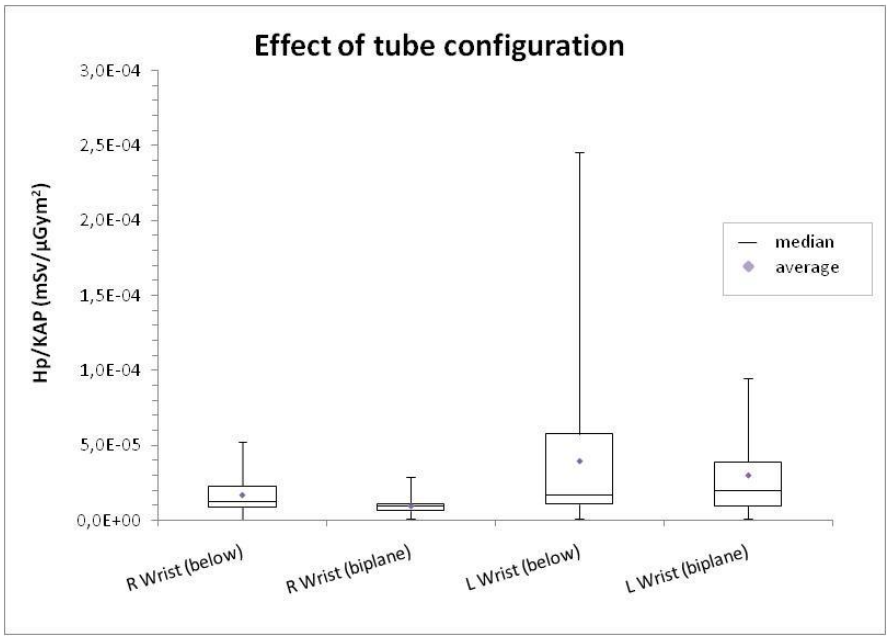
The effect of tube configuration is performed for the cases with femoral access and when ceiling shields (for the eyes, wrists and fingers) or table shields (for the legs) are used. The results are presented in the following graphs.



Below: 97 cases
Biplane: 20 cases

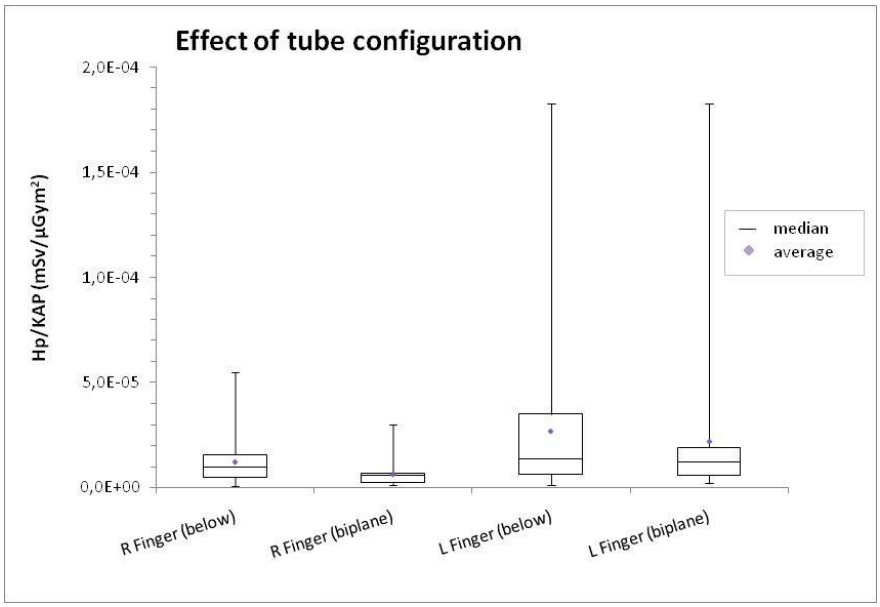
Left Eye	Middle Eye	
biplane/below		
0.5	0.3	for median

Graph 100: The effect of the tube configuration to the eye doses for femoral access and the ceiling suspended shield is present



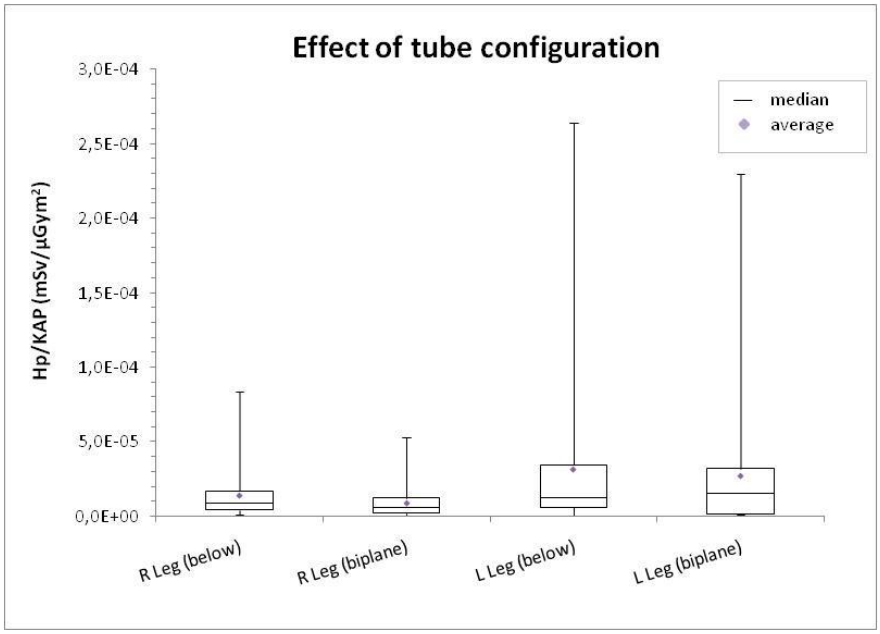
Left Wrist	Right Wrist	
biplane/below		
1.2	0.7	for median

Graph 101: The effect of the tube configuration to the wrist doses for femoral access and the ceiling suspended shield is present



Left Finger	Right Finger	
biplane/below		
0.9	0.6	for median

Graph 102: The effect of the tube configuration to the finger doses for femoral access and the ceiling suspended shield is present



Below: 112 cases
Biplane: 27 cases

Left Leg	Right Leg	
biplane/below		
1.3	0.6	for median

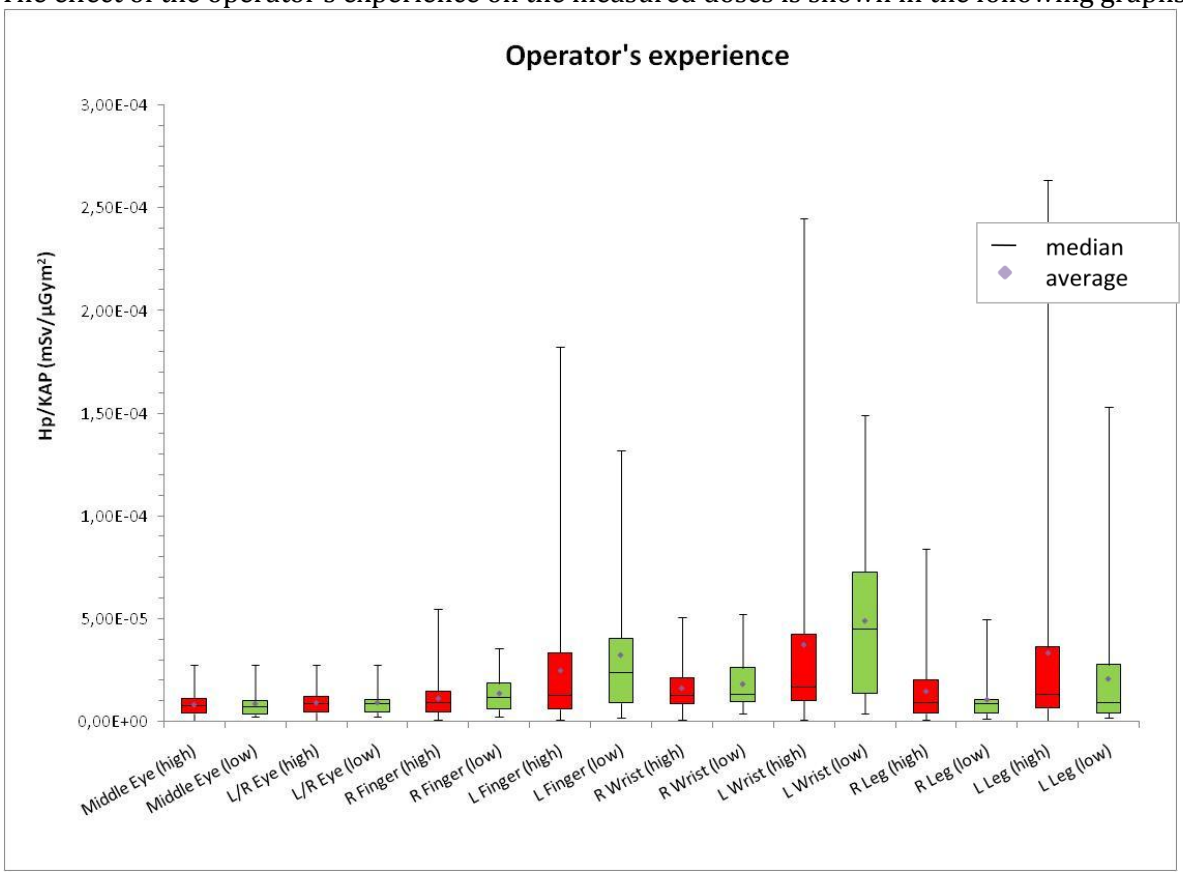
Graph 103: The effect of the tube configuration to the leg doses for femoral access and the table shield is present

For the fingers, wrist and legs doses are comparable between biplane systems and tube-below configurations. This is also proven by the ANOVA analysis. There is an effect of the tube configuration on the eye dose. In the biplane cases the eye doses are lower than in the cases where the tube is below the table. In these cases the eyes are either very well protected by the ceiling or lateral suspended shield or they are protected by the image intensifier of the other tube.

The above analysis is not performed for the radial access since there were a few cases with bi plane systems.

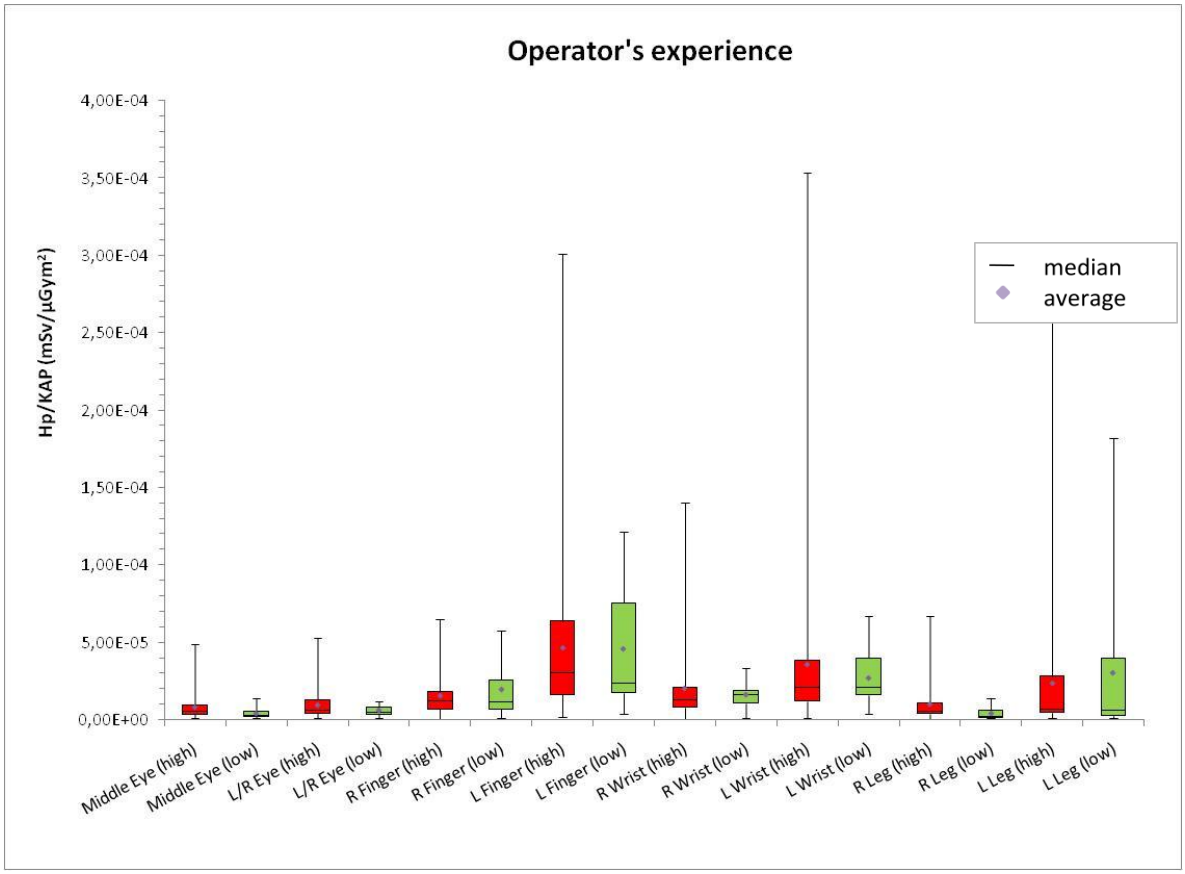
2.6.3 Experience

The effect of the operator's experience on the measured doses is shown in the following graphs.



Graph 104: The effect of the operator's experience on the Hp/KAP values for tube below configuration, femoral access, ceiling suspended shield and table shield present

For femoral access there are significant differences in Hp(0.07)/KAP values for left finger, left wrist and left leg (the high experienced personnel have lower doses, for the legs it is the other way around); in the remaining positions the doses are comparable.

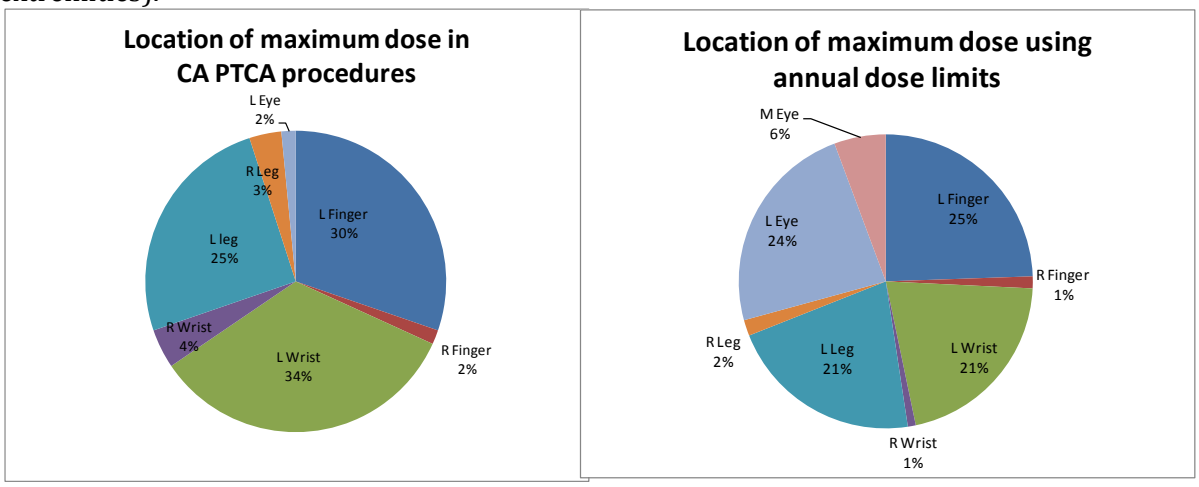


Graph 105: The effect of the operator's experience on the H_p/KAP values for tube below configuration, radial access, ceiling suspended shield and table shield present

In radial access the H_p/KAP values are, in general, higher for the highly experienced operators than for the ones with low experience or comparable.

2.6.4 Position of the maximum

For the position of the maximum two pie charts are presented: one with the frequency of the position where the maximum dose was recorded and the other with the maximum dose recorded divided by the respective annual limits (150 mSv for the eyes and 500 mSv for the extremities).



Graph 106: Position of the maximum dose (on the left) and maximum dose divided by the respective annual limit (on the right)

The maximum dose is measured more frequently on the left hand (finger and wrist) and on the left leg. However, when the location of the maximum dose is calculated using the respective annual doses limits, the left hand, leg and eye lens are almost equally distributed.

2.6.5 Maximum doses

The following table presents the maximum doses and the respective conditions during which these doses were measured.

Table 5: The table presents the maximum doses in each dosimetric position and the conditions during which these doses were measured

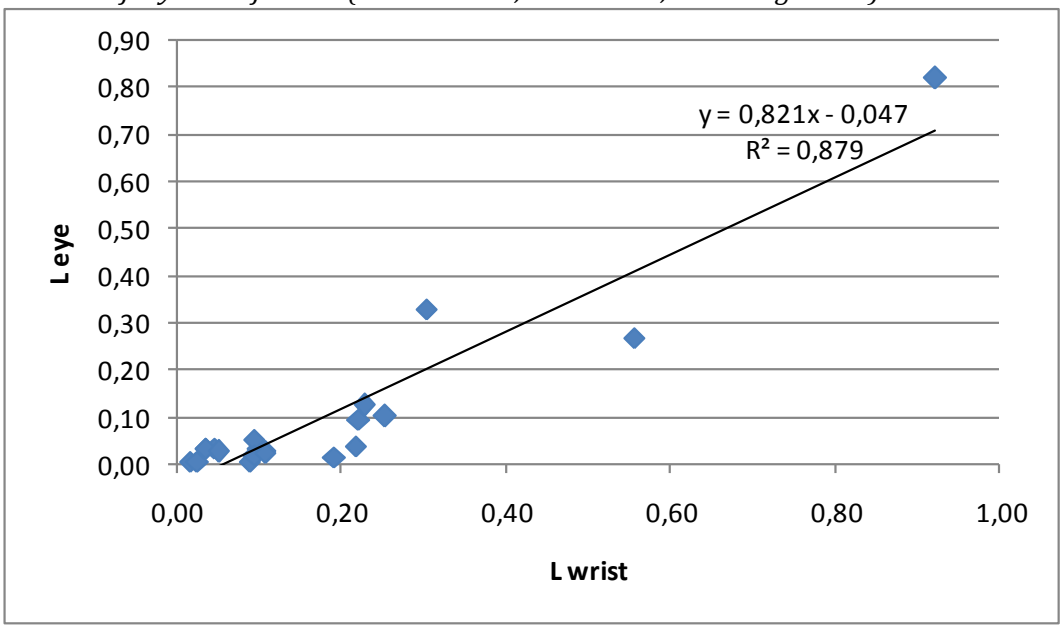
	L Finger	R Finger	L Wrist	R Wrist	L Leg	R Leg	L Eye	Middle Eye
$H_p(0.07)$ [mSv]	5.0	0.5	1.8	0.6	1.6	1.2	0.8	0.6
type	CA & PTCA	CA	PTCA	CA	CA & PTCA	PTCA	CA & PTCA	
experience	low	low	high	high	low	high	high	
tube	below	below	biplane	biplane	biplane	biplane	below	
access	femoral	radial	femoral	femoral	femoral	femoral	radial	
protective equipment	table, patient	table, ceiling	table	table ceiling	table, ceiling	table, ceiling	table	
KAP [µGym²]	23597	19881	40458	38409	6827	-	19152	

The maximum dose that was recorded to the hands was 5 mSv to the left finger of a low experienced operator, during a therapeutic procedure. 0.8 and 0.6 mSv were recorded to the eyes during a therapeutic procedure where radial access was used and there was no ceiling suspended shield present. Finally, the highest doses to the legs (1.6 mSv and 1.2 mSv to the left and right leg respectively) were measured when operators used the biplane technique.

2.6.6 Correlations

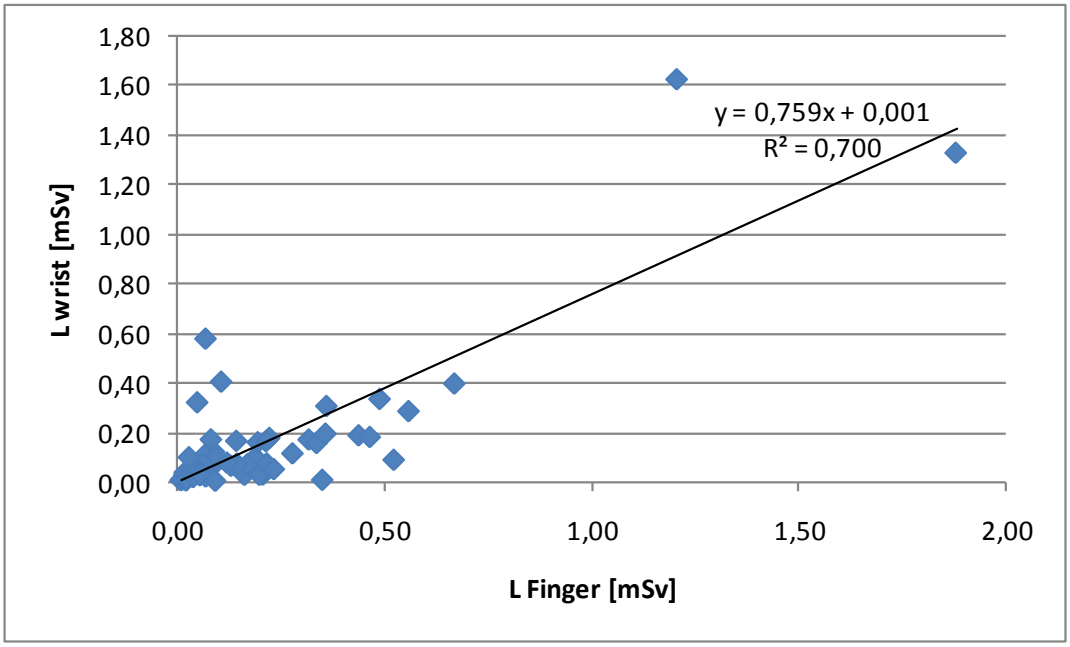
The parameters that were found to be correlated are:

- *Left eye↔ Left wrist (radial access, tube below, no ceiling shield)*



Graph 107: Correlation between the Left Eye and Left Wrist values for radial access when the tube is below and there is no shield

- *Left finger↔Left wrist (radial access, tube below and ceiling shield present)*



Graph 108: Correlation between the Left Wrist and Left Finger values for radial access when the tube is below and there is ceiling shield

2.6.7 Conclusions

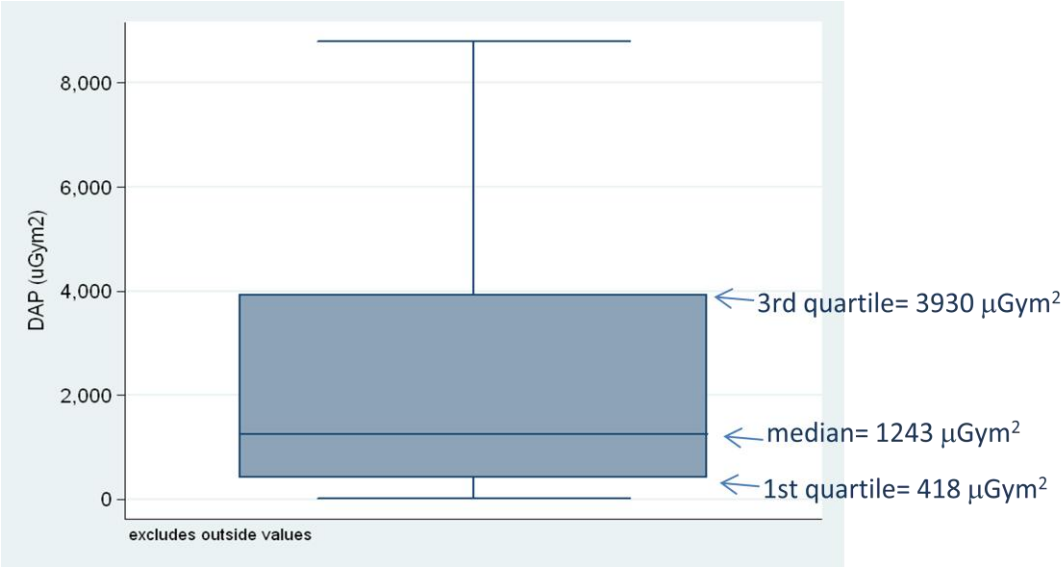
- Protective equipment
  - For the femoral access the effect of protective equipment is observed and is statistically important only for the legs; 1.3 to 3.5 times reduction
  - For the radial access the effect of the ceiling shield on the dose reduction is statistically important for eyes (1.6 to 2.3 times), wrists (1.3 to 1.7 times) and fingers (1.3 to 1.6 times)
- Access
  - When the ceiling suspended shield is absent, the doses to the eyes, wrists and fingers are lower (1.2 to 4.8 times) for the femoral access compared to the radial one
  - When the ceiling suspended shield is present, the influence of the access on the doses to the eyes, fingers and wrists becomes less important. In some cases the doses are even higher for femoral access, as it is more difficult for the operator to properly shield himself when he is further from the X-ray beam
  - When the ceiling suspended shield is present, the influence of the access on the doses to the eyes is not statistically important. The doses to the hands are higher in the radial access than in the femoral
  - When the table shield is used the influence of the access on the leg doses is not statistically important.
- Experience: the influence of experience is not clear for its affect on the doses.

Tube configuration: In general bi-plane systems gave lower doses as in these cases better shielding was used and because the operator can be shielded by the image intensifier of the vertical tube.

2.7 *Pacemaker and Cardiac Defibrillator implantations (PM)*

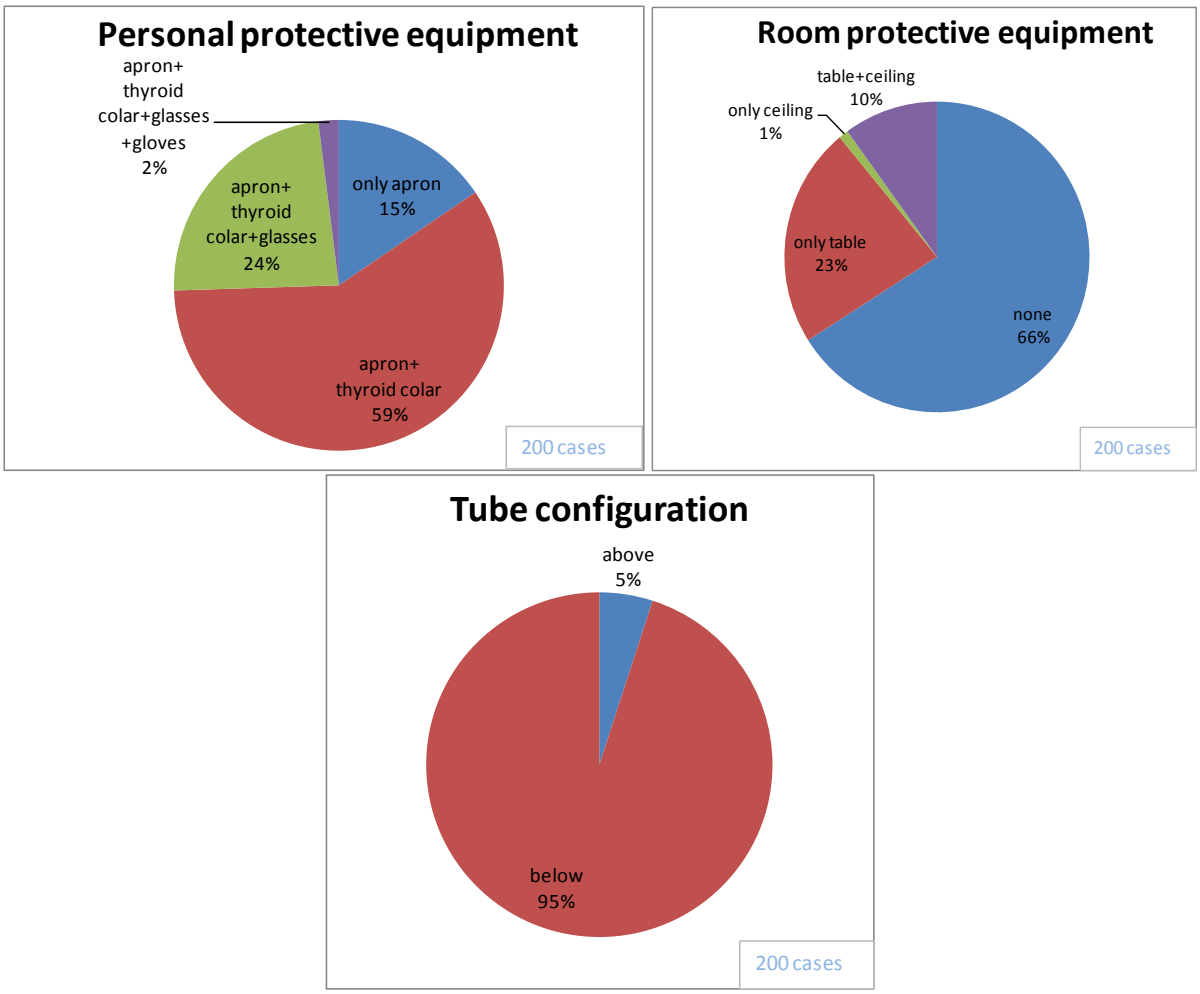
2.7.1 General information

In total 200 procedures were monitored in 14 hospitals. The following graph presents the box plot with the respective KAP values.



Graph 109: Box plot with the KAP values for all the monitored pacemaker procedures

In the next graphs some statistics are presented giving information on the use of the room protective equipment.

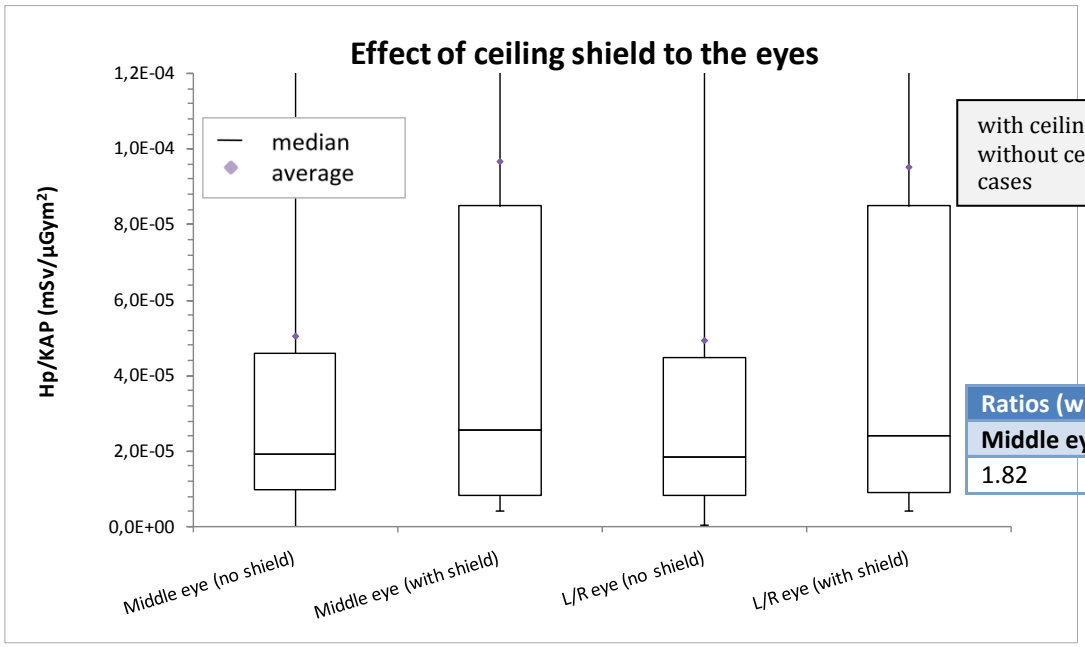


Graph 110: Statistics concerning the use of the personal and room protective equipment, and tube configuration.

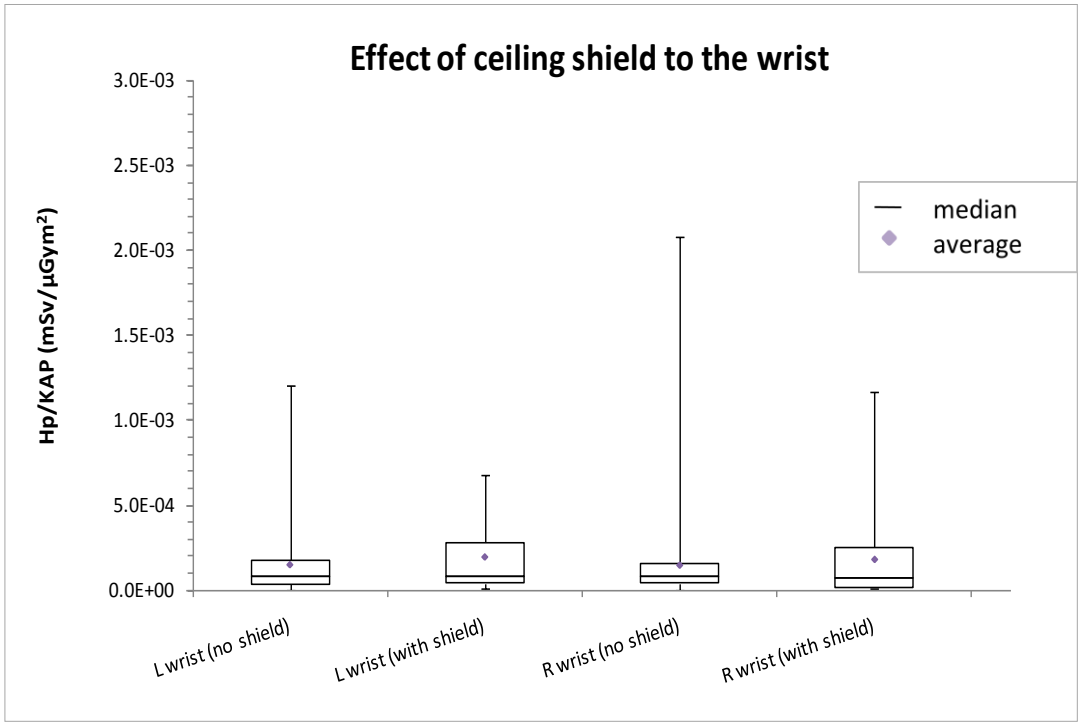
Concerning the personal protective equipment most of the operators use the lead apron and thyroid collar, however only 26% use protective glasses. The lead glasses are important for the protection of the eye lenses during these procedures, since the ceiling suspended shield is rarely used because the operators work very close to the primary beam and the ceiling shield obstructs their work. Moreover, the table shield was absent or was not covering the operators' legs most of the times. During such procedures the operators stand close to the patient's head or shoulder and use both sides of the operating table. Finally, 95% of the measurements were performed using undercouch irradiation.

2.7.2 Effect of room protective equipment and tube configuration

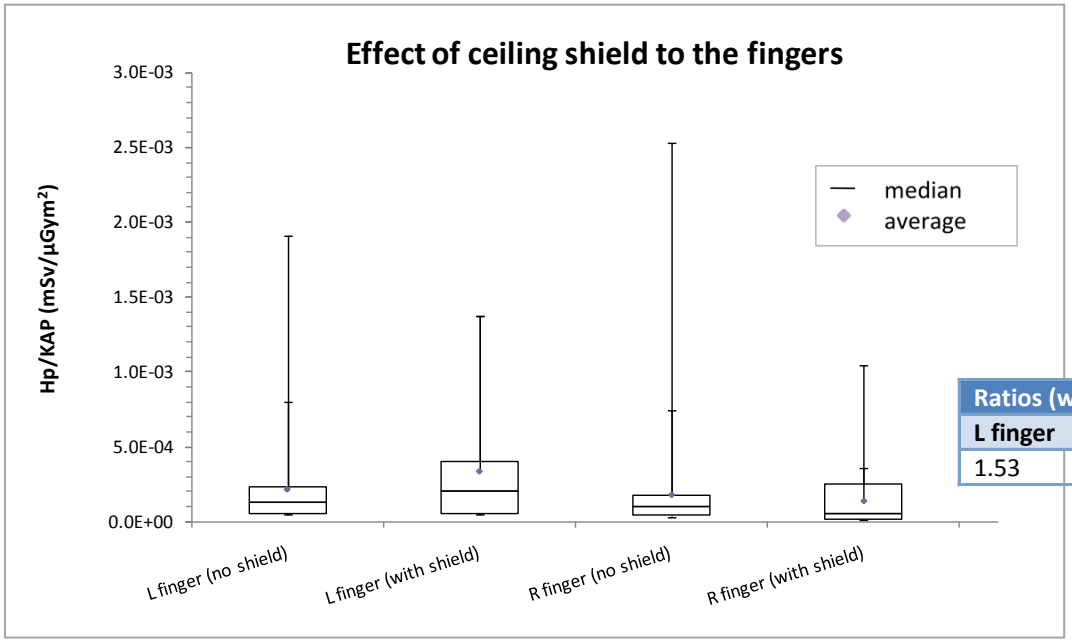
The use of ceiling suspended shield was studied for the effect on the reduction of the eye, finger and wrist doses. The results are presented in the following graphs. The reduction ratio is also calculated.



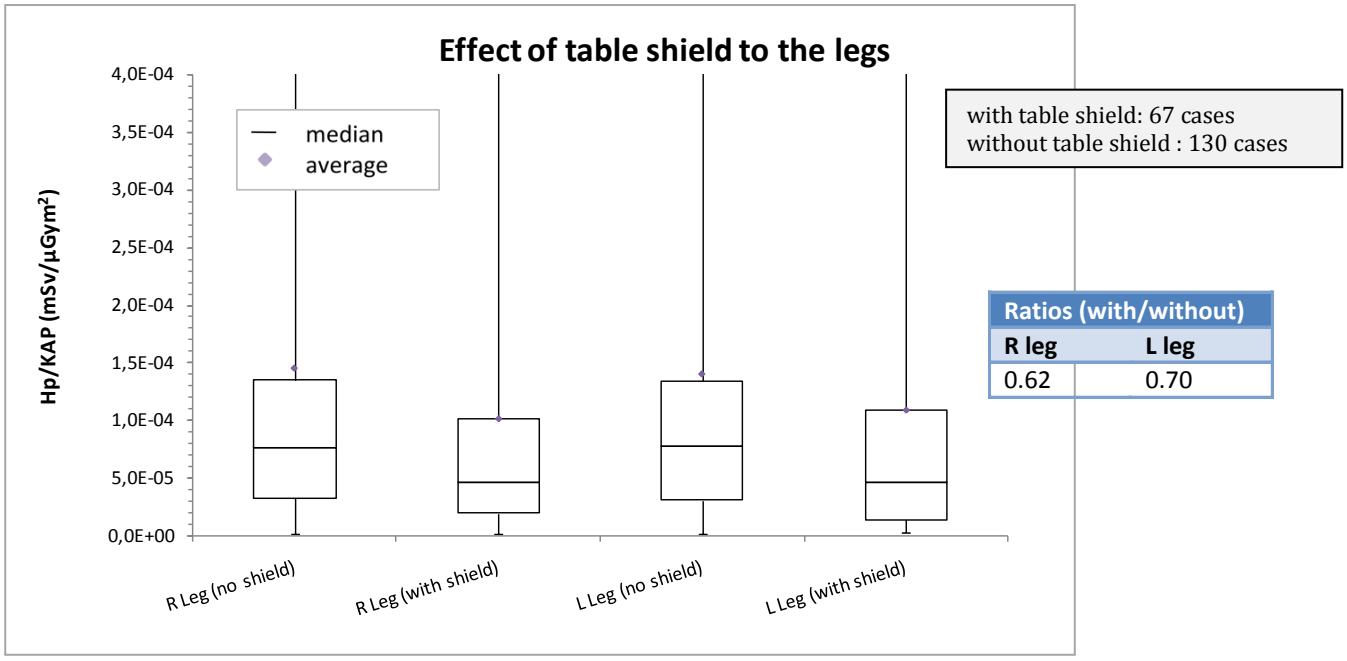
Graph 111: The effect of the ceiling suspended shield to the eye doses (ZOOM graph)



Graph 112: The effect of the ceiling suspended shield to the wrist doses



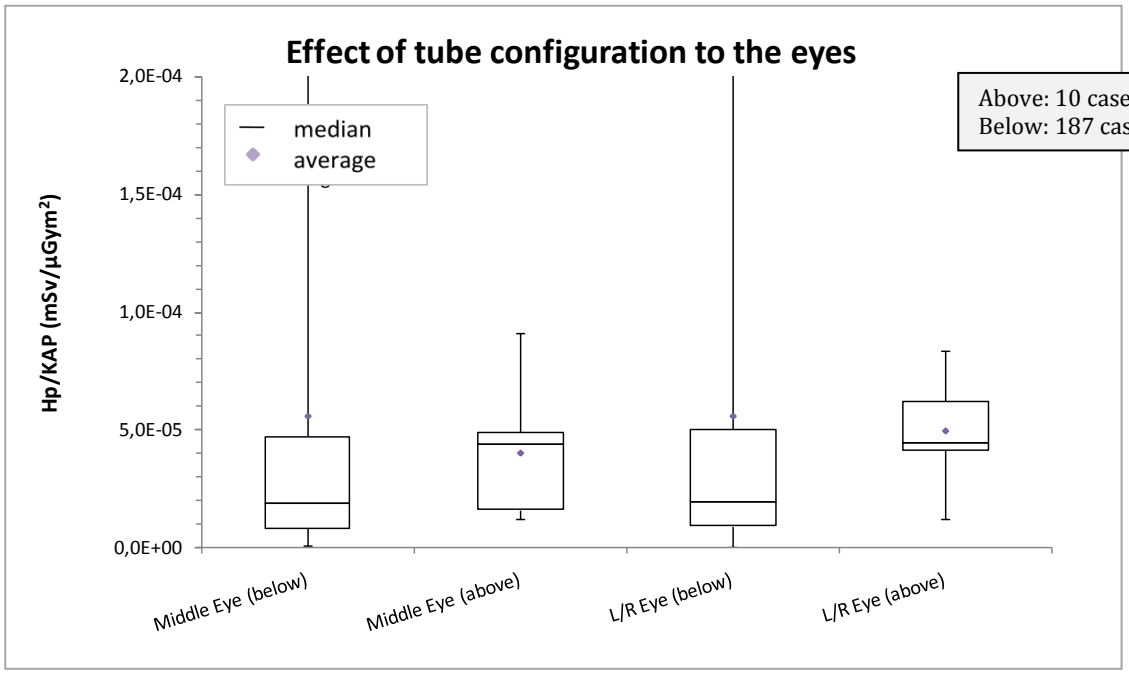
Graph 113: The effect of the ceiling suspended shield to the finger doses



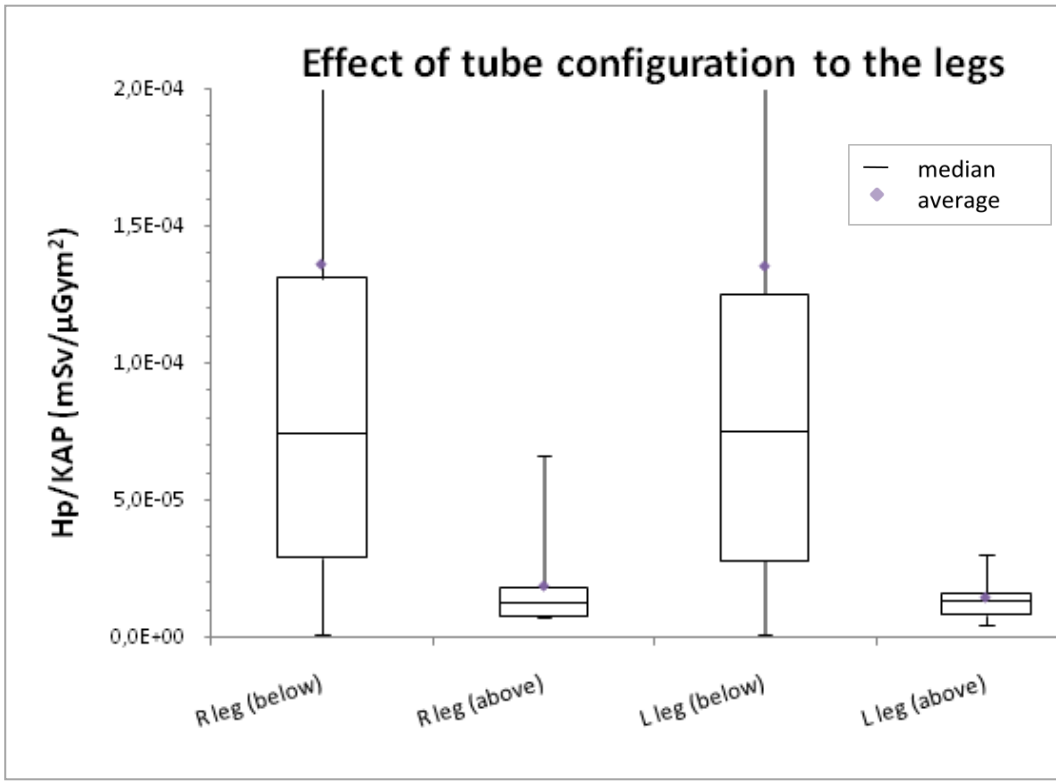
Graph 114: The effect of the ceiling suspended shield to the leg doses (ZOOM graph)

As it is shown from the above graphs the use of table shield has a clear influence on the leg doses. There is no effect of the ceiling suspended shield to the hands and eye doses and this is also proven by the ANOVA tests. This can be explained due to the fact that the hands are very close to the primary beam during PM and ICD implantations and even when the ceiling shield is used the hands are not protected. Also the number of cases where the ceiling shield was used was small. As far as the eyes are concerned the image intensifier plays the role of a shield as the operators stand very close to the primary beam so the effect of ceiling suspended shield is not statistically important.

In the next graph the effect of the tube configuration is studied for the effect on the eye and leg doses.



Graph 115: Effect of tube configuration to the eye doses (ZOOM graph)



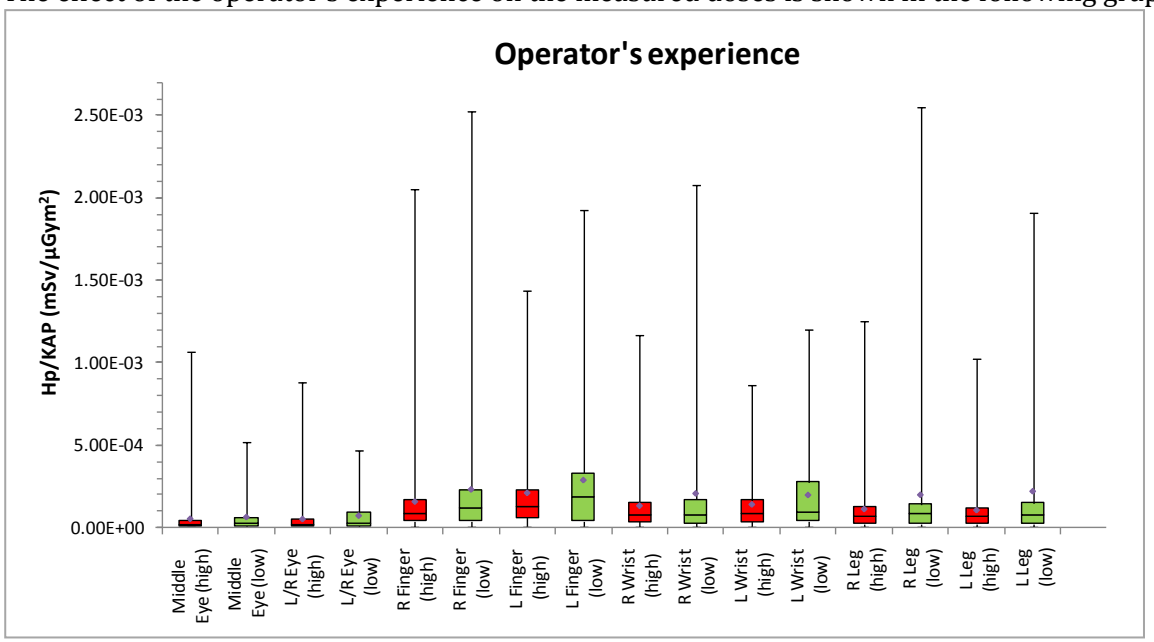
ratios (above/below)	
Left Leg	Right Leg
0.11	0.10

Graph 116: Effect of tube configuration to the leg doses (ZOOM graph)

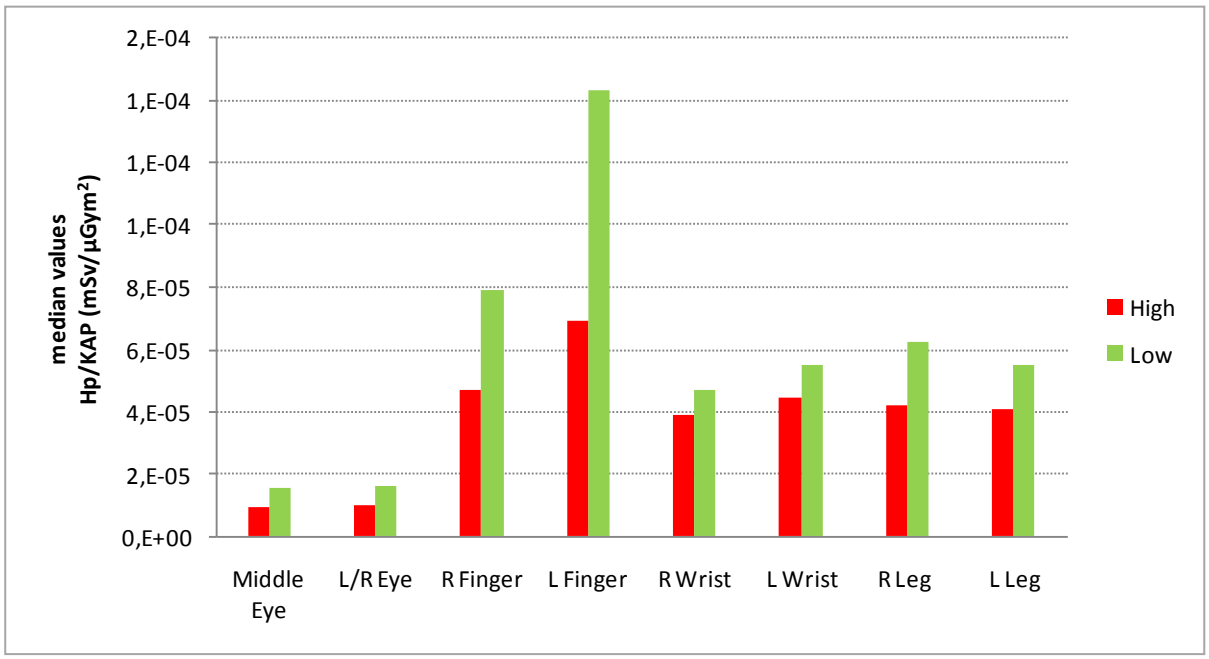
As expected the eye doses are higher when the tube is positioned above the operating table, while for the legs the situation is the opposite.

2.7.3 Experience

The effect of the operator's experience on the measured doses is shown in the following graphs.



Graph 117: The effect of the operator's experience on the H_p/KAP values

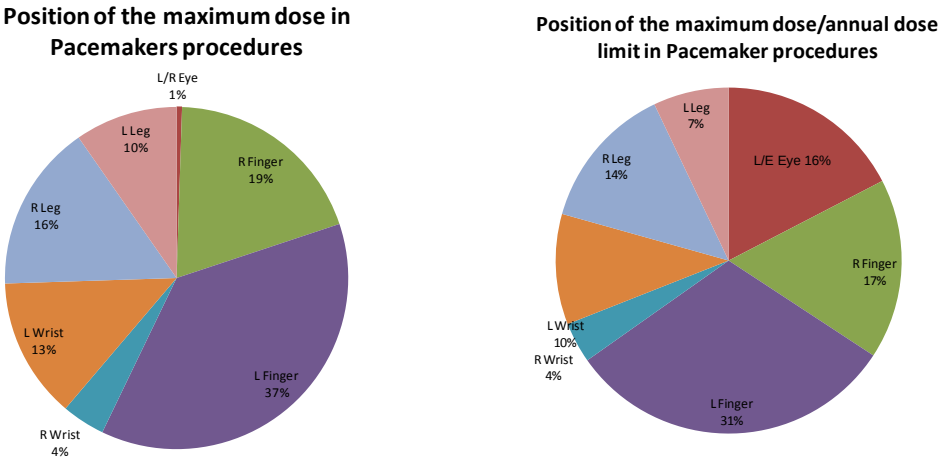


Graph 118: The median H_p values for high and low experienced operators.

The doses in all positions are higher for the low experienced personnel.

2.7.4 Position of the maximum

For the position of the maximum two pie charts are presented: one with the frequency of the position where the maximum dose was recorded and the other with the maximum dose recorded divided by the respective annual limits (150 mSv for the eyes and 500 mSv for the extremities).



Graph 119: Position of the maximum dose (on the left) and maximum dose divided by the respective annual limit (on the right)

The maximum dose was recorded on the left finger most of the times. However, taking into account the respective annual limits for all positions the left eye comes into the scene with a frequency of the maximum doses of 17%.

2.7.5 Maximum doses

The following table presents the maximum doses and the respective conditions for which these doses were measured.

Table 6: The table presents the maximum doses in each dosimetric position and the condition during which these doses were measured

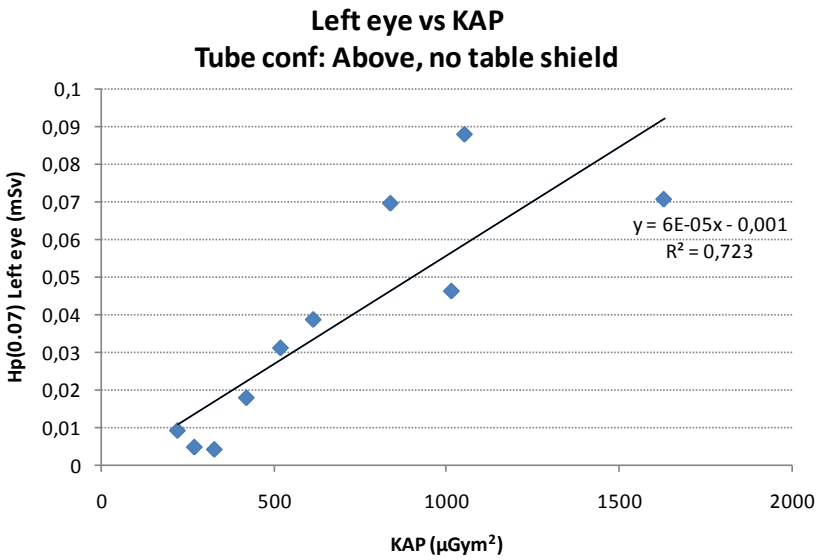
	L Finger	R Finger	L Wrist	R Wrist	L Leg	R Leg	L/R Eye	Middle Eye
Maximum Dose (mSv)	**6.54**	**4.33**	**4.82**	**3.83**	**7,82**	**5.00**	**1.08**	**0.81**
Protective equipment	none	none	none	none	none	none	none	
Tube configuration	below	below	below	below	below	below	below	
Comments		Hands in beam		Hands in beam				

From the above table it is seen that the highest doses are measured when no protective equipment is used or when the hands are inside the beam field.

2.7.6 Correlations

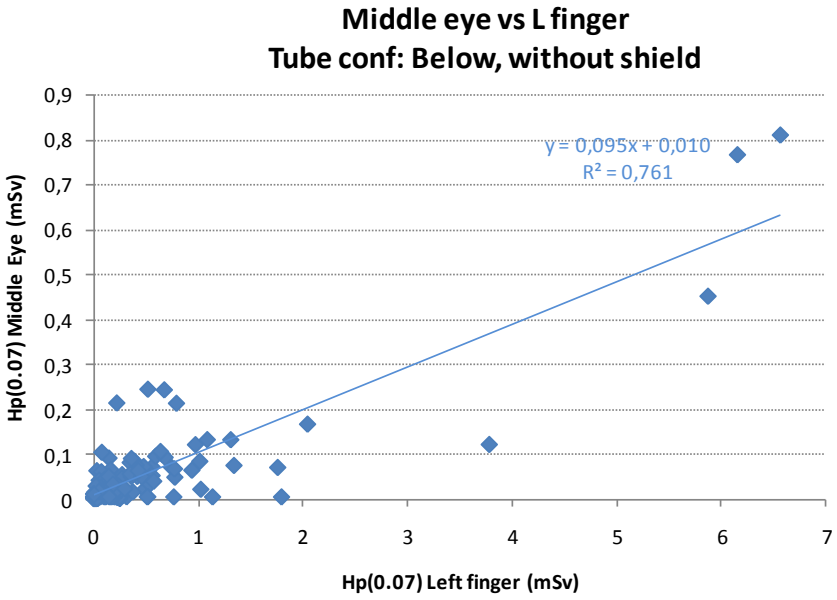
The parameters that were found to be correlated are:

- *Left eye↔KAP (ceiling shield absent, tube above, R^2=0.72)*



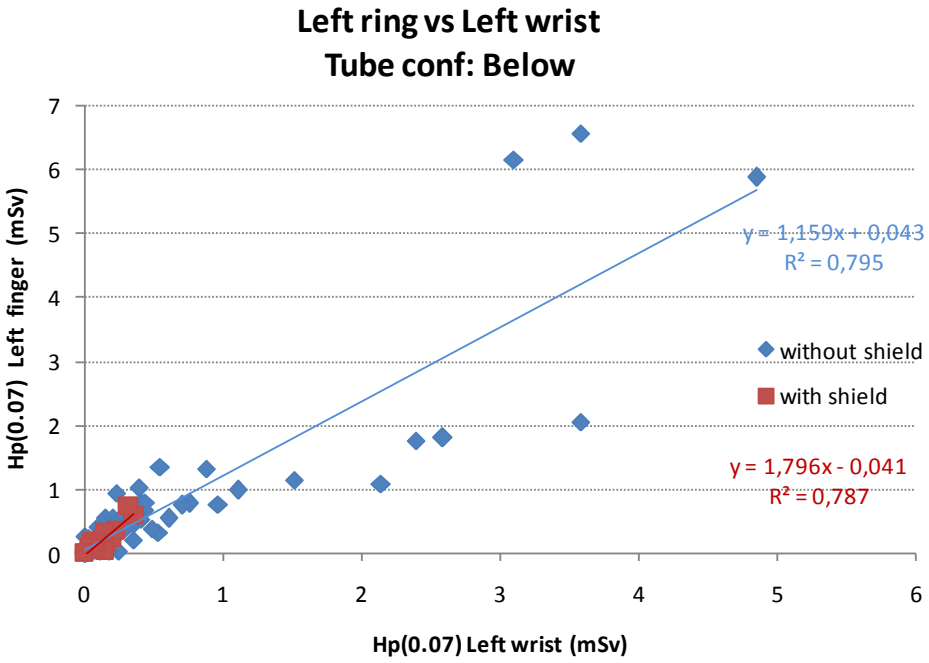
Graph 120: Correlation between the Left Eye and KAP values when the tube is above and there is no shield

- *Middle eye↔Left finger (tube below, ceiling shield absent, R^2=0.76)*



Graph 121: Correlation between the Middle and Left finger doses when the tube is below and there is no shield

- *Left finger↔Left wrist (tube below, ceiling shield absent R^2=0.8)*



Graph 122: Correlation between the Left finger and left wrist doses when the tube is below (with and without shield)

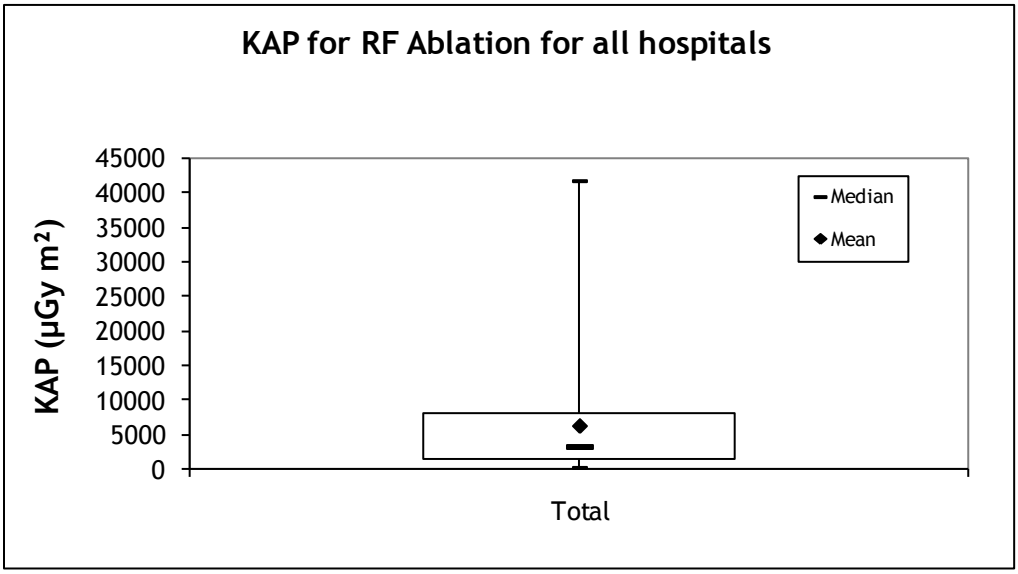
2.7.7 Conclusions

- Effect of the protective equipment: There is a clear influence of the table shield on leg doses (1.5 times reduction), especially when the tube is below the operating table. There is no influence of the ceiling suspended shield on eye and hand doses
- Effect of the tube configuration: there is a statistically important influence of the tube configuration on the eye and leg doses. The eye doses are higher when the tube is above the operating table, while the leg doses are higher when the tube is below the operating table (9 times reduction)
- Experience: Lower doses were found for the highly experienced operators for all dosimetric positions
- The maximum dose was measured most often on the left finger

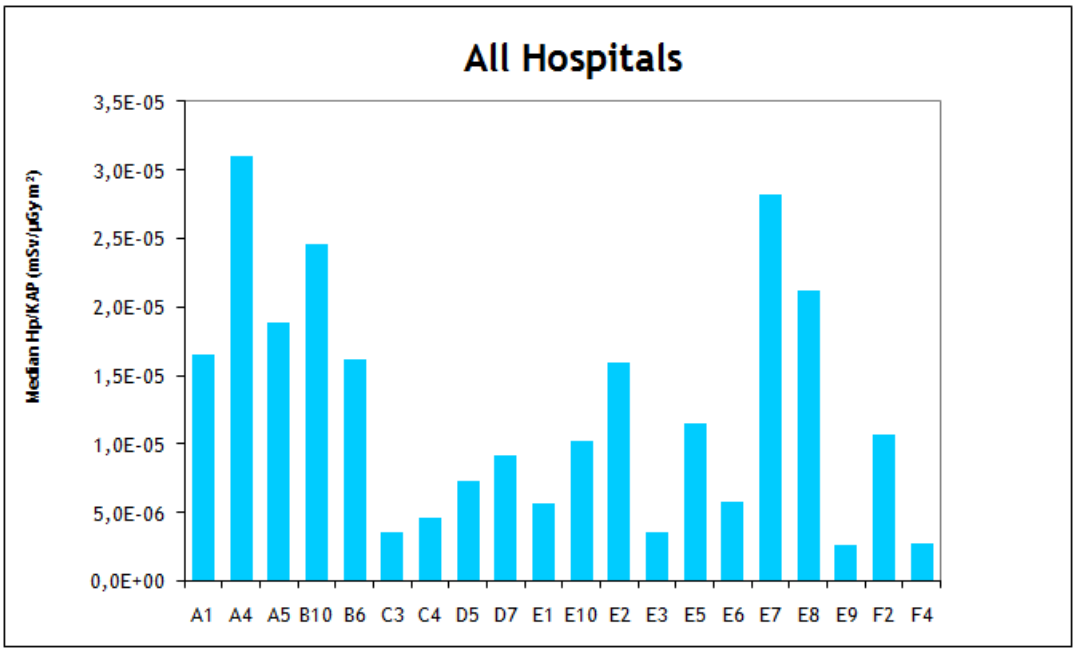
2.8 Radiofrequency ablations (RF)

2.8.1 General information

In total 191 procedures were monitored in 14 hospitals. The following graph presents the box plot with the respective KAP values and the next one, the median KAP values at the various hospitals.

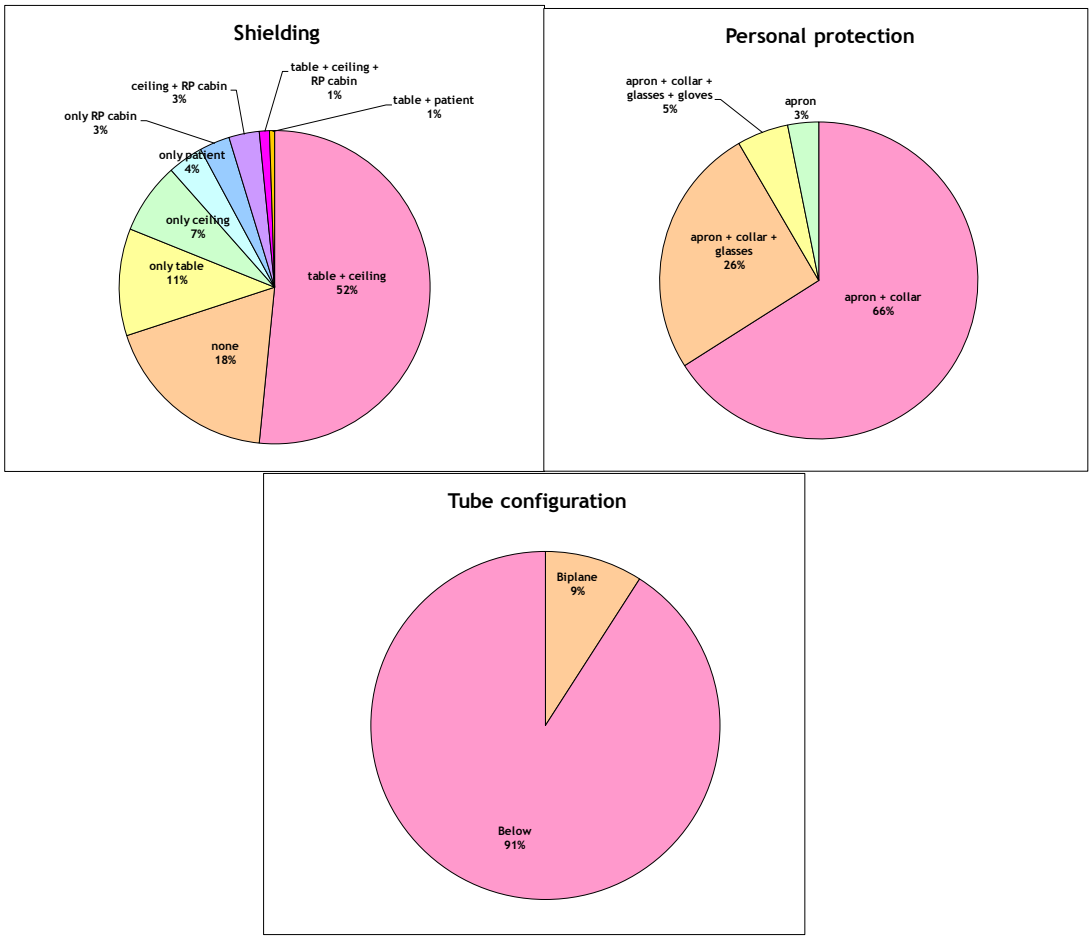


Graph 123: Box plot with the KAP values for all the monitored RF procedures



Graph 124: Median KAP values at the various hospitals where the measurement campaign for the RFA procedures took place

In the next graphs some statistics are presented giving information on the frequency of the use of the room protective equipment, personal protective equipment and tube configuration.

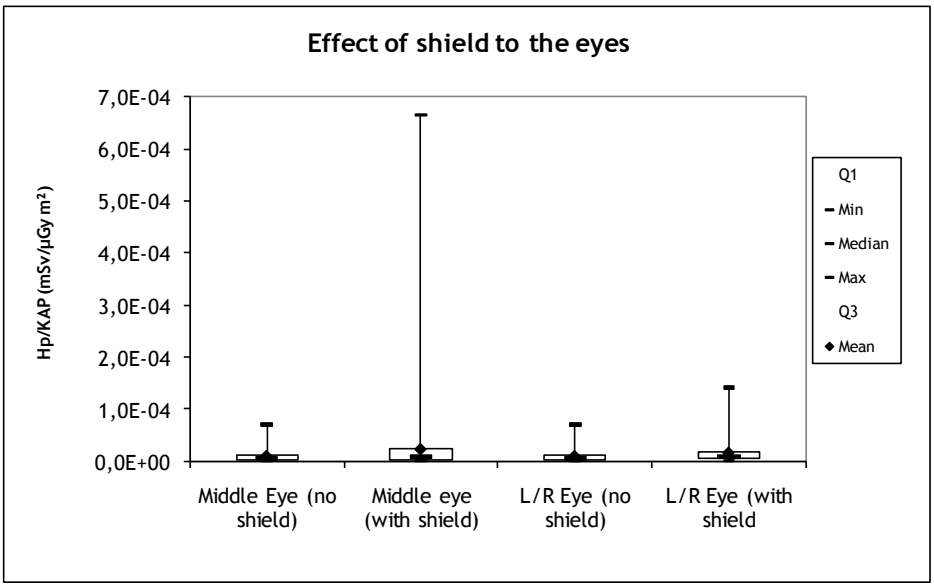


Graph 125: Statistics with the use of the room protective equipment, personal protective equipment, tube configuration and whether the operator goes outside or stays inside during the cine mode

Table and ceiling suspended shields were both used in the majority of the cases. However, 18% did not use any kind of protective shield. As for the personal protection, lead apron and thyroid collar were almost always used, but lead glasses were used only in 31% of the cases. The use of lead gloves was also encountered during this type of procedure in a small number of cases. Finally, undercouch irradiation was used in 91% of the measurements and only 9% used the biplane technique.

2.8.2 Effect of room protective equipment, tube configuration and in/out during cine parameter

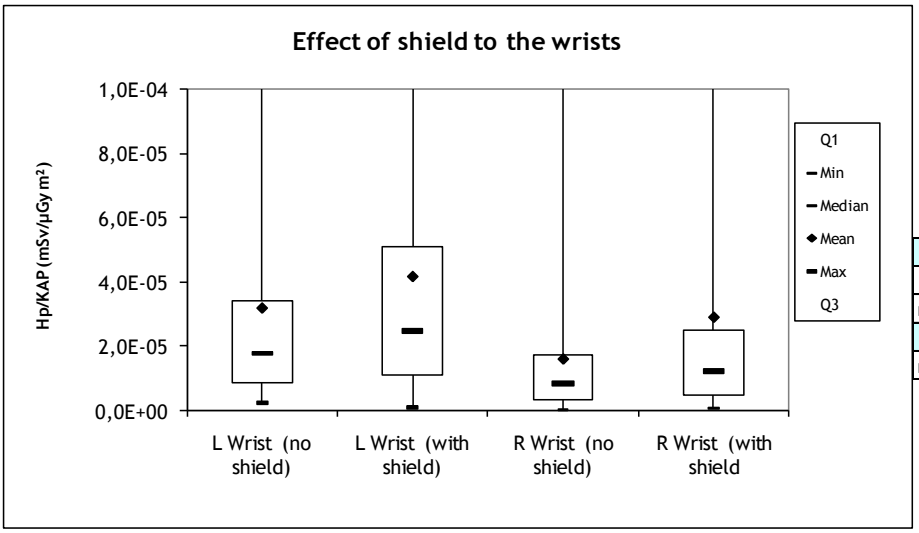
The use of ceiling suspended shield was studied for the effect on the reduction on the eye, finger and wrist doses. The results are presented in the following graphs. The reduction ratio is also calculated using the median values.



with ceiling shield: 109 cases
without ceiling shield : 56 cases

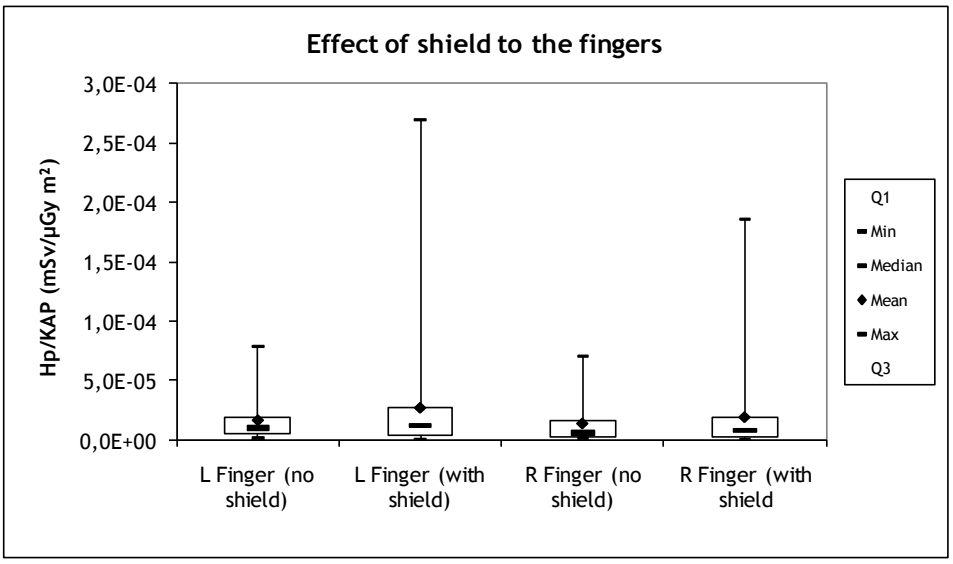
% reduction		
	M Eye	L/R Eye
median	158%	160%
Ratio (without/with)		
median	0,63	0,63

Graph 126: The effect of the ceiling suspended shield to the eye doses



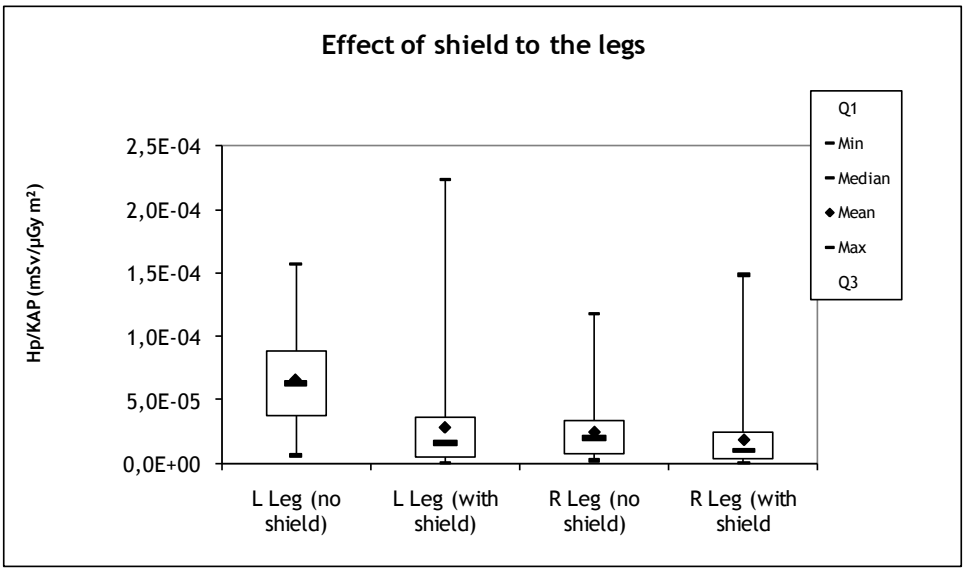
% reduction		
	L Wrist	R Wrist
median	139%	145%
Ratio (without/with)		
median	0,72	0,69

Graph 127: The effect of the ceiling suspended shield to the wrist doses



% reduction		
	L Finger	R Finger
median	114%	134%
Ratio (without/with)		
median	0,88	0,75

Graph 128: The effect of the ceiling suspended shield to the finger doses



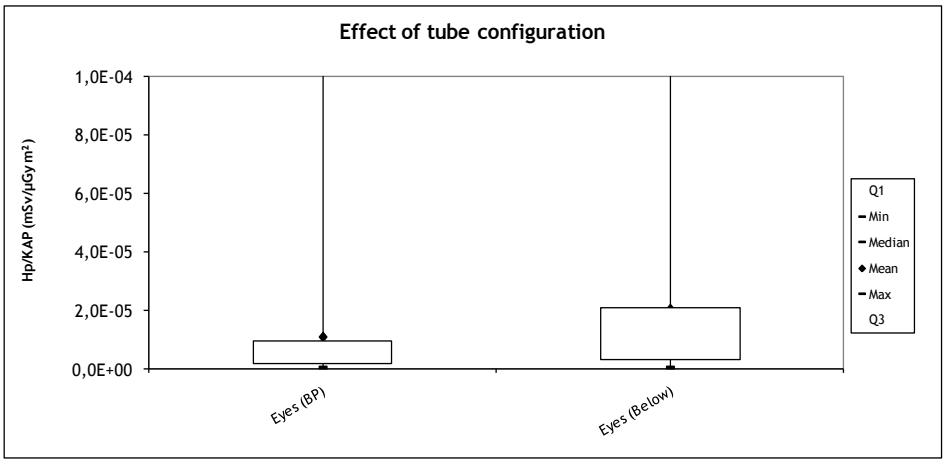
with table shield: 132 cases
without table shield : 49 cases

% reduction		
	L Leg	R Leg
median	25%	53%
Ratio (without/with)		
median	3,96	1,89

Graph 129: The effect of the ceiling suspended shield to the leg doses (ZOOM graph)

As it is seen from the above graphs there is again no statistically important influence of the ceiling shield on the eye, finger and wrist doses. Also for this kind of procedure, tube below configurations are mainly used. However, the influence of the table shield is statistically important for the leg doses; the respective reduction ratio ranges from 1.9 to 4.

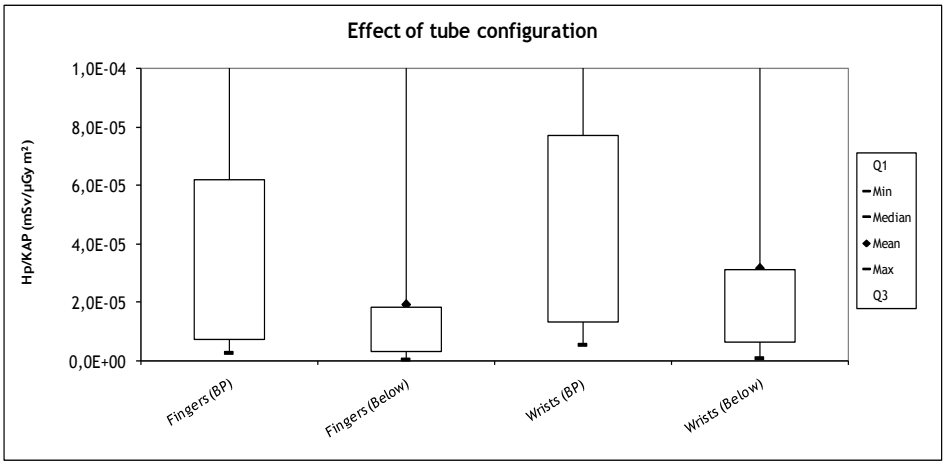
In the following graphs the effect of tube configuration is studied for the effect on the eye, finger and wrist doses.



Population		
	BP	Below
N	32	205
Measurements	16	103

% reduction	
	Legs
median	329%
Ratio (BP/Below)	
median	0,30

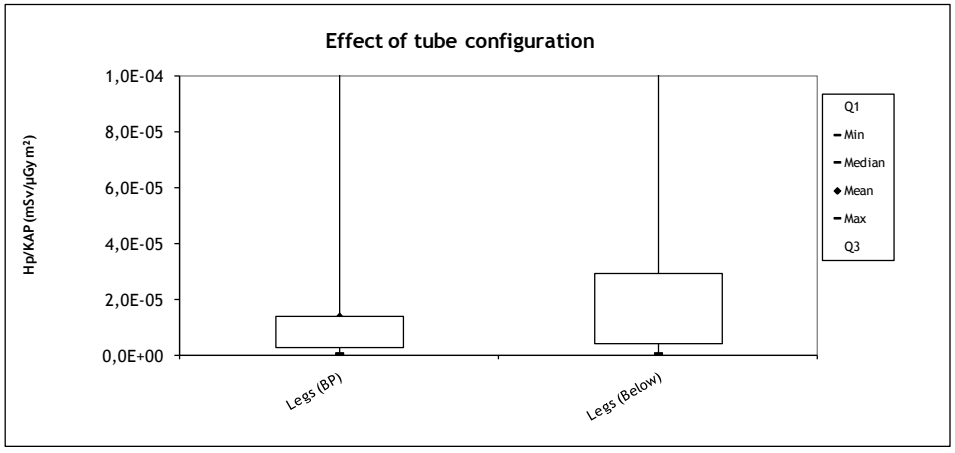
Graph 130: Effect of tube configuration to the eye doses when the ceiling suspended shield is used



Population		
	BP	Below
N	19	168
Measurements	10	84

% reduction		
	Fingers	Wrists
median	53%	59%
Ratio (BP/Below)		
median	1,90	1,70

Graph 131: Effect of tube configuration to the finger and wrist doses when ceiling suspended shield is used



Population		
	BP	Below
N	30	225
Measurements	16	113

% reduction	
	Legs
median	38%
Ratio (Below/BP)	
median	2,61

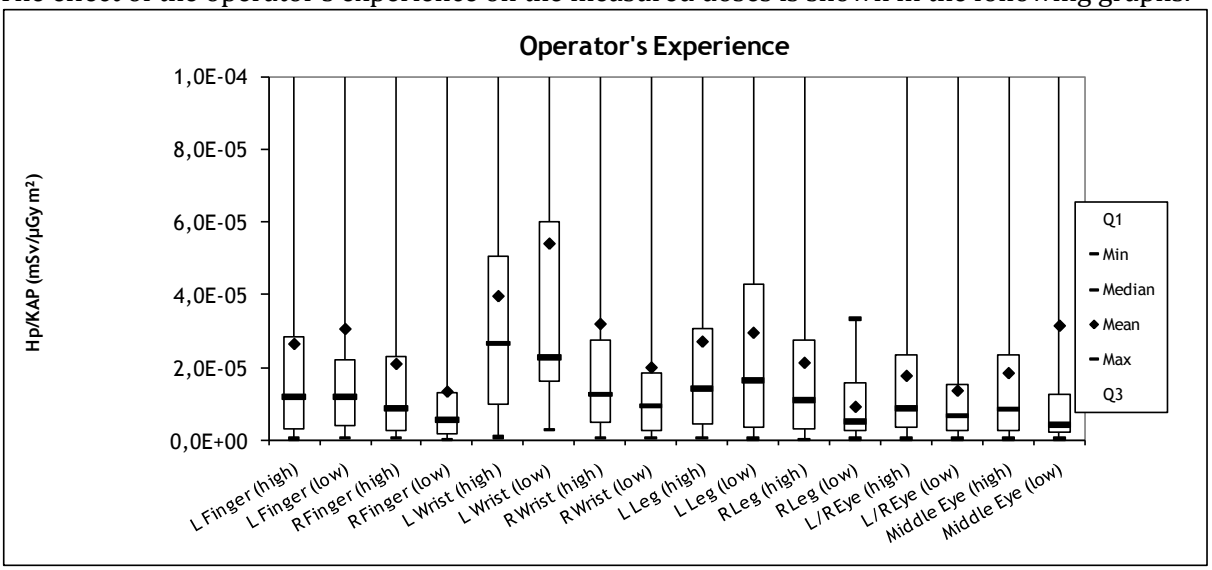
Graph 132: Effect of tube configuration to the leg doses when protective table shield is used

There is a statistically important effect of the tube configuration on the leg doses. The doses are higher 2.6 times when the tube is below the operating table. The same effect is observed for the eyes; in the bi plane systems the eye doses are lower by 3 times than in the cases where the tube is positioned below the operating table. As far as the hands are concerned the doses are higher in the biplane systems.

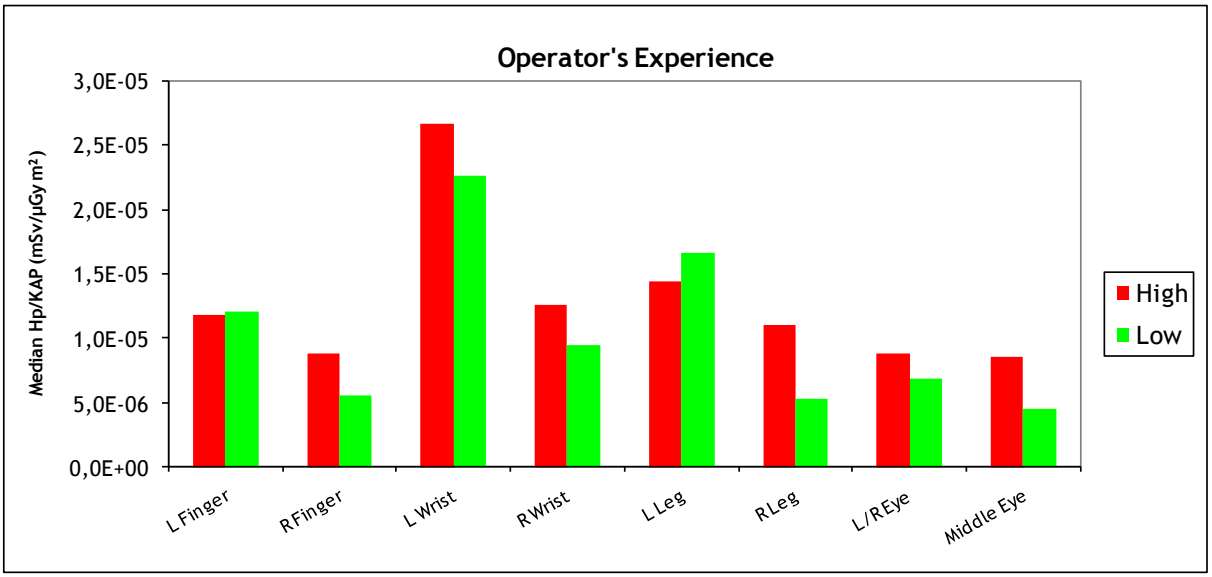
Moreover, from the multi parameter analysis it was shown that for the biplane technique the eye, finger and wrist doses are higher in case there is the ceiling protection. This is probably due to the fact that in these cases the shield was not properly used.

2.8.3 Experience

The effect of the operator's experience on the measured doses is shown in the following graphs.



Graph 133: The effect of the operator's experience on the H_p/KAP values shielded cases

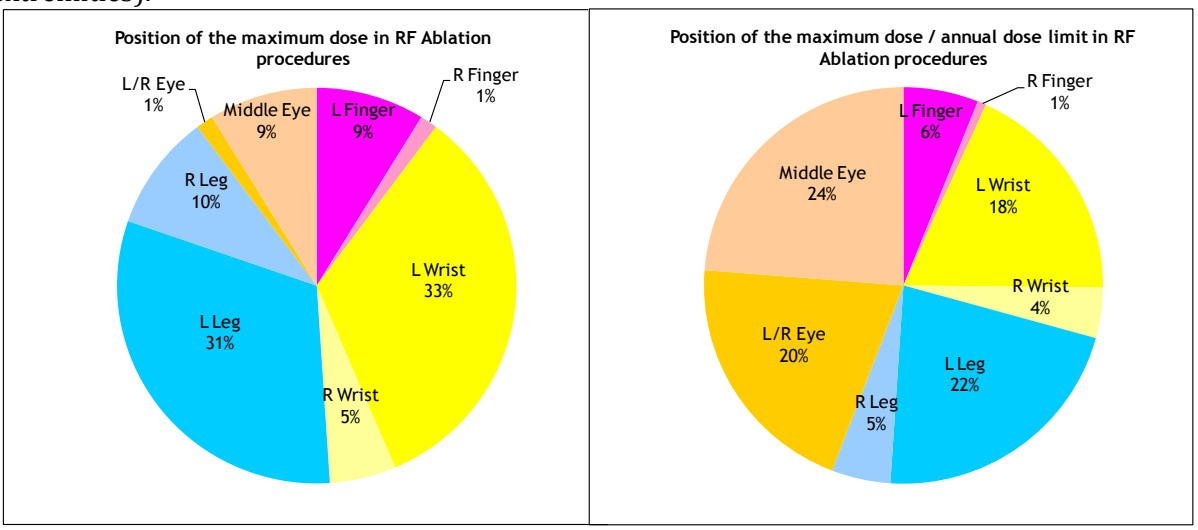


Graph 134: The median H_p/KAP values for high and low experienced operators.

The H_p/KAP values are lower for the low experienced personnel, not for the left leg. However, as proved by the ANOVA test, experience does not influence the doses at a statistically significant level.

2.8.4 Position of the maximum

For the position of the maximum two pie charts are presented: one with the frequency of the position where the maximum dose was recorded and the other with the maximum dose recorded divided by the respective annual limits (150 mSv for the eyes and 500 mSv for the extremities).



Graph 135: Position of the maximum dose (on the left) and maximum dose divided by the respective annual limit (on the right)

The maximum dose was recorded most often on the left wrist (33%) and then on the left leg (31%). However, taking into account the annual limits for all positions the exposure to the eyes and left leg become the most important.

2.8.5 Maximum doses

The following table presents the maximum doses and the respective conditions during which these doses were measured.

Table 7: The table presents the maximum doses in each dosimetric position and the condition during which these doses were measured

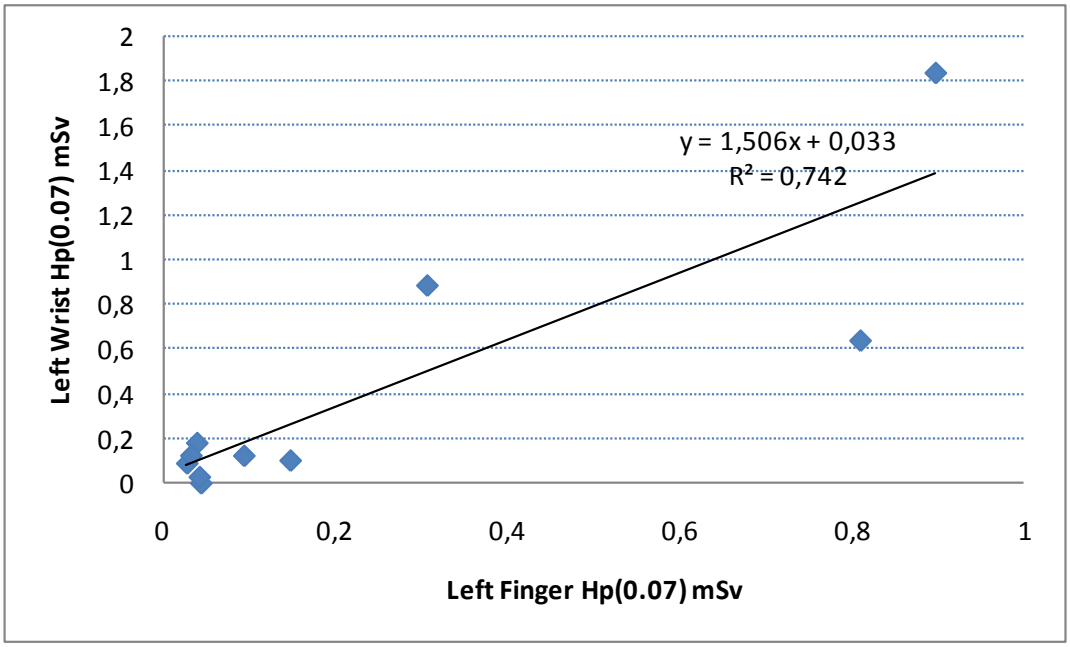
	L Finger	R Finger	L Wrist	R Wrist	L Leg	R Leg	L/R Eye	Middle Eye
$H_p(0.07)$ [mSv]	0.90	0.45	1.84	0.53	1.82	0.78	0.88	0.63
Protection	table + ceiling	table	table + ceiling	none	ceiling	patient	table	
Tube	biplane	below	biplane	below	below	below	below	
Total KAP ($\mu Gy.m^2$)	25400	16300	25400	5394	20400	24900	16300	

From the above table it is seen that even though there was a ceiling shield the left wrist has received a considerable high dose due to the fact that it was not properly shielded from the biplane tube. As far as the eyes are concerned the high doses are explained due to the absence of ceiling shield. Finally, in almost all of the cases with maximum values in the table are lying in the region of high KAP values.

2.8.6 Correlations

The parameters that were found to be correlated are:

- *Left Finger with Left wrist for biplane techniques and shielded cases*



Graph 136: *Correlation between the Left wrist and Left finger doses when in biplane techniques and shielded cases*

However, it should be mentioned that systematic positive correlations are clearly observed between different positions, particularly for the biplane and shielded configuration, eg between L Finger and L Wrist as illustrated on the above graph. This is also the case between measured doses and KAP values. For the tube below configuration, legs appear to be better correlated with KAP for unshielded than for shielded configurations. However, although values larger than 0.8 are frequently observed, it has to be mentioned that no general trend can be deduced from the data. So the dose to the operator, whatever the position of interest (fingers, legs, eyes, etc.) cannot be estimated from the KAP, and reciprocally; also the dose to any position cannot be deduced from its knowledge at another position. Finally, it was checked for some cases that the lower detection limit values do not induce a bias in the correlation strong enough to affect the previous conclusions

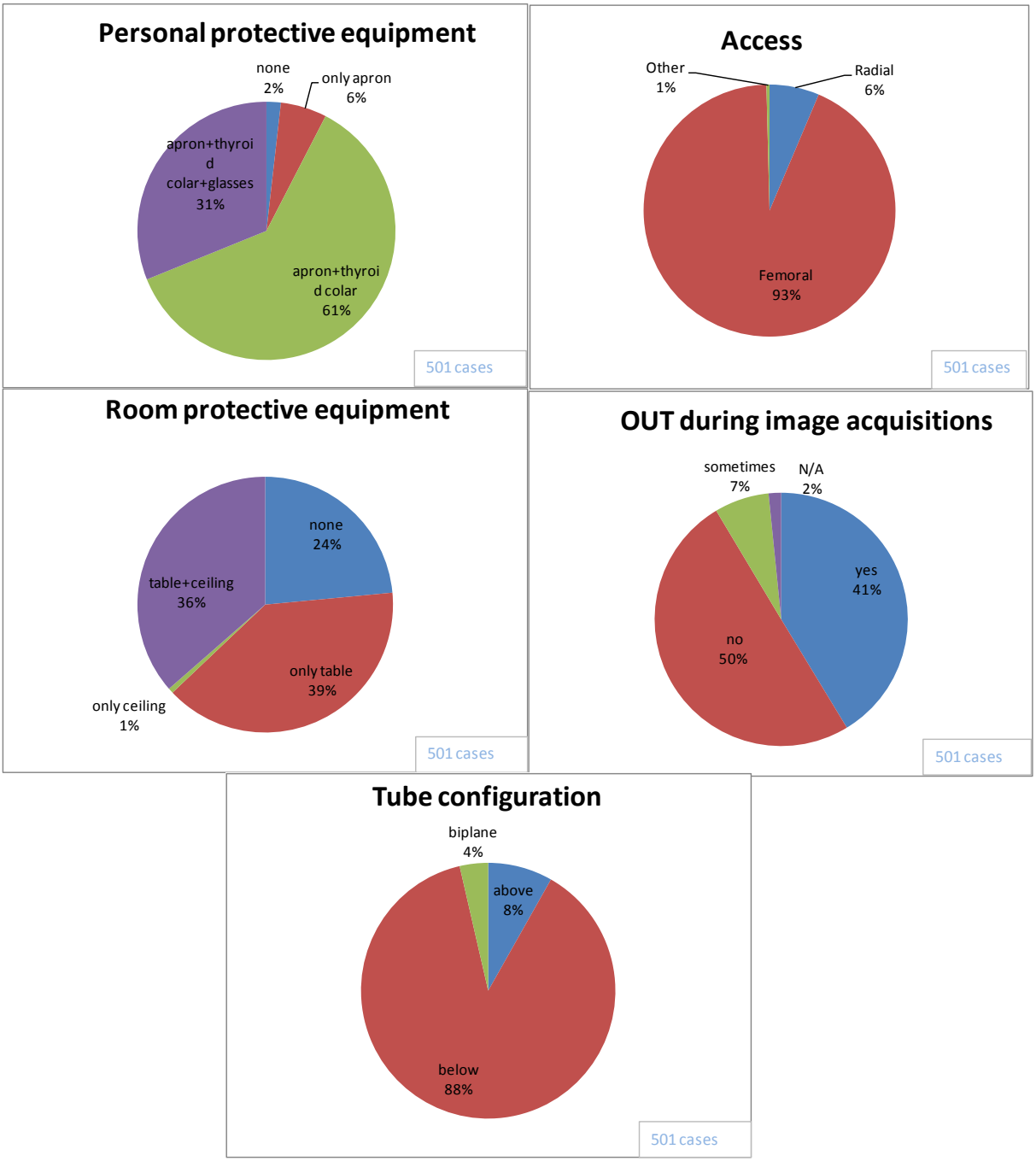
2.8.7 Conclusions

- Effect of protective equipment: The effect of the table shield is statistically important in reducing the leg doses (by 1.9 to 4 times). As far as the effect of the ceiling suspended shield is concerned, although it is evident that it strongly attenuates the X-rays, the effect of its use on the doses measured to the fingers, the wrists and the eyes in not seen in the data. The reason is that theses shields are not properly used
- Effect of tube configuration: The legs are influenced more by the tube configuration. The leg doses are higher 2.6 times when the tube is below the table. The same effect is observed for the eyes where the reduction ratio is 3. The hand doses are higher in biplane systems than in the cases where the tube is below the operating table, maybe because the ceiling or lateral shield is not properly used
- The maximum doses were mostly recorded on left wrist, but when taking into account the respective annual limits the eye exposure becomes most important
- The experience is not considered as a parameter that can influence the doses at a statistically important level

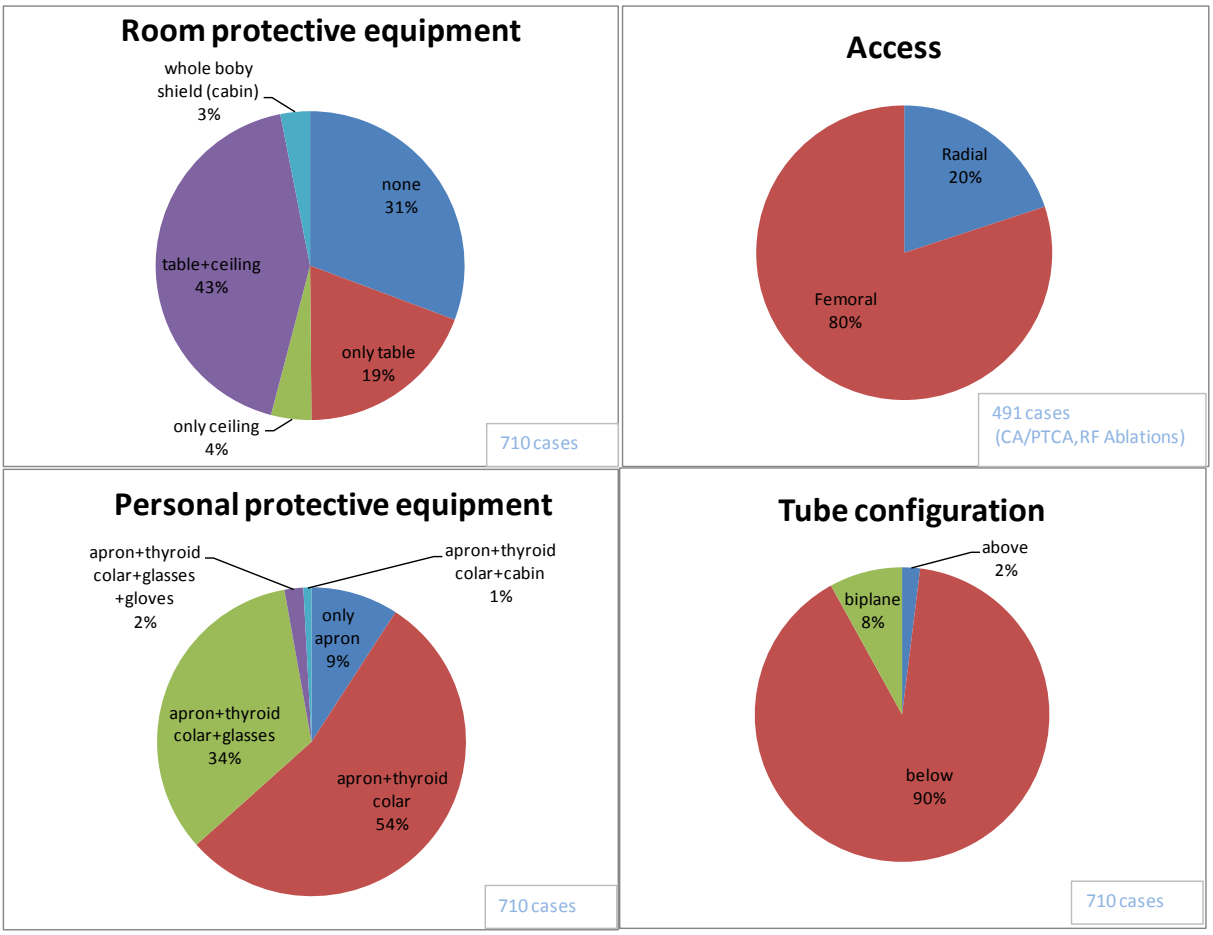
2.9 Summary

In this session some statistics are presented giving information on the frequency of the use of the room protective equipment, personal protective equipment, tube configuration and access of the catheter. The different types of procedures have been divided in three categories:

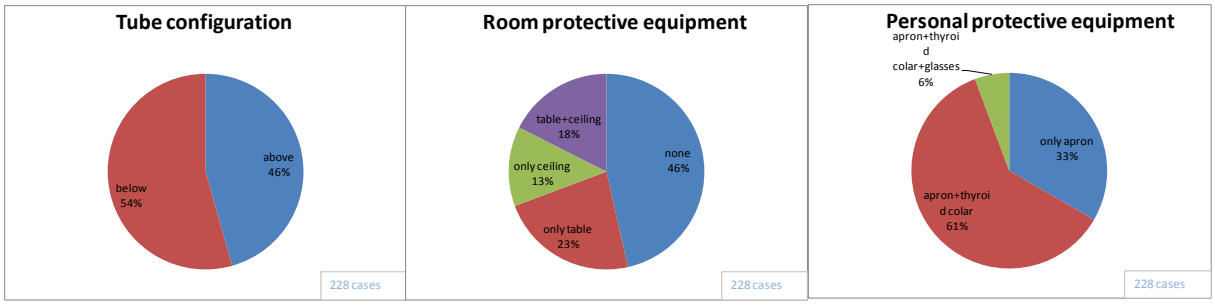
interventional radiology (DST PTA of LL, RE, Ca Ce and Embolizations), interventional cardiology (CA, PTCA, PM and RFA) and ERCP.



Graph 137: Statistics in *interventional radiology* with the use of the room and personal protective equipment, tube configuration, access, and whether the operator goes outside of the room during the image acquisitions



Graph 138: Statistics in *interventional cardiology* with the use of the room and personal protective equipment, tube configuration and access



Graph 139: Statistics in *ERCP procedures* with the use of the room and personal protective equipment and tube configuration

As it can be seen from the above chart pies the majority of the operators wear protective apron and thyroid collar. Only 2% of the operators in IR do not use any personal protective equipment. Protective eye glasses are used in more than 30% in the interventional radiology and cardiology procedures, but only 6% use them in ERCP ones. A 2% of the operators use protective gloves in IR procedures. The small percentage is mainly due to the fact that the gloves are not so comfortable. Special protective equipment like radiation protection cabin and floor movable shield were met in a few cases.

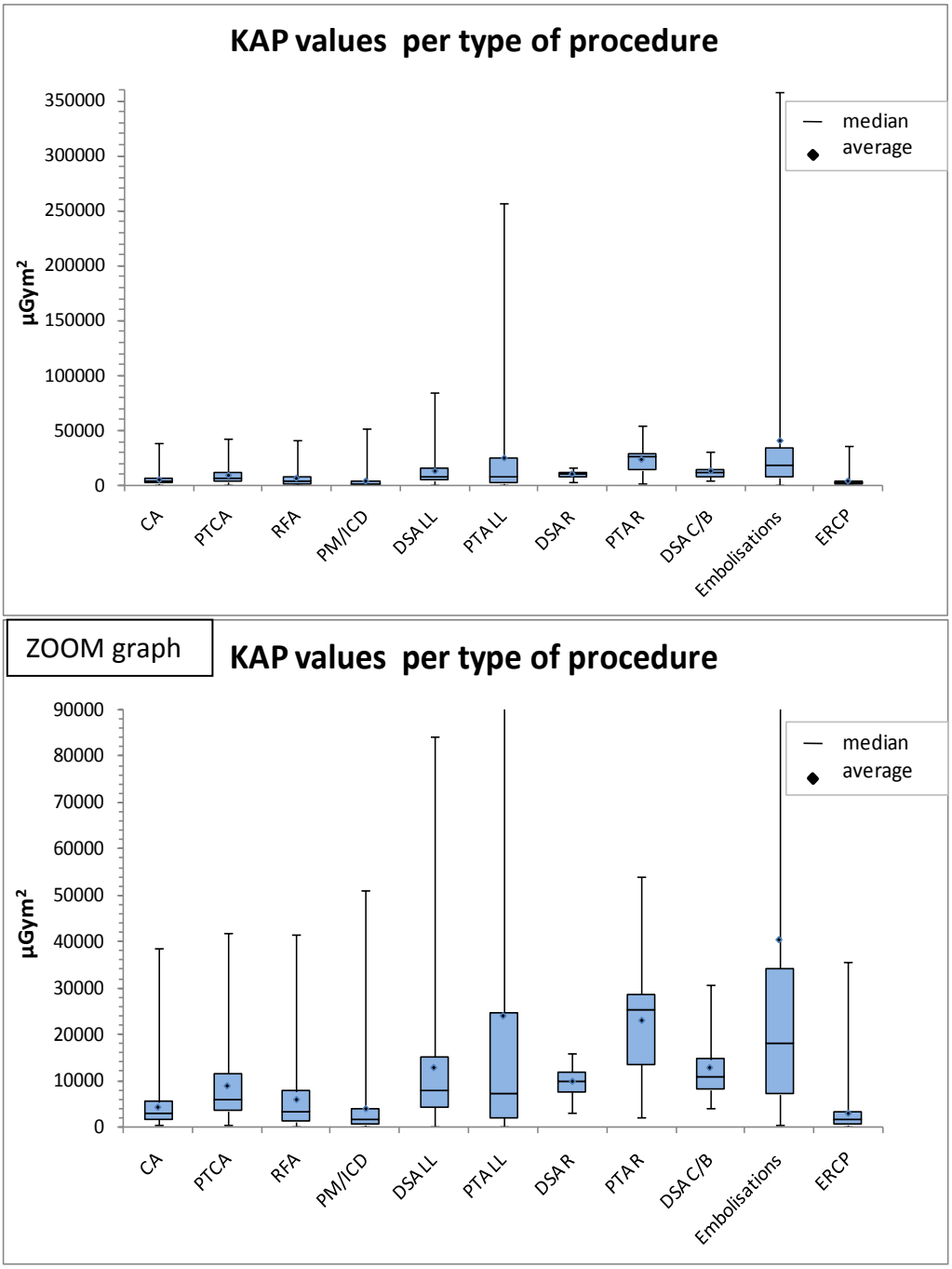
For the room protective equipment, it is noted that there is a percentage of more than 24% who does not use any room protective equipment. As it can be seen from the graphs the table shield is more favorable than the ceiling one; it is used in the majority of the cases that were monitored.

As far as the tube configuration is concerned, the below the operating table cases are most frequent in almost 90% in IC and IR procedures. There were cases where biplane systems are used. For the ERCP procedures it is noted that there is a large percentage of cases (46%) where the tube is positioned above the operating table.

From the pie chart is it seen that the femoral access is preferred than the radial one, especially in the IR sector.

Finally it is seen that in half of the cases in IR procedures the operator is staying inside the room during the image acquisitions.

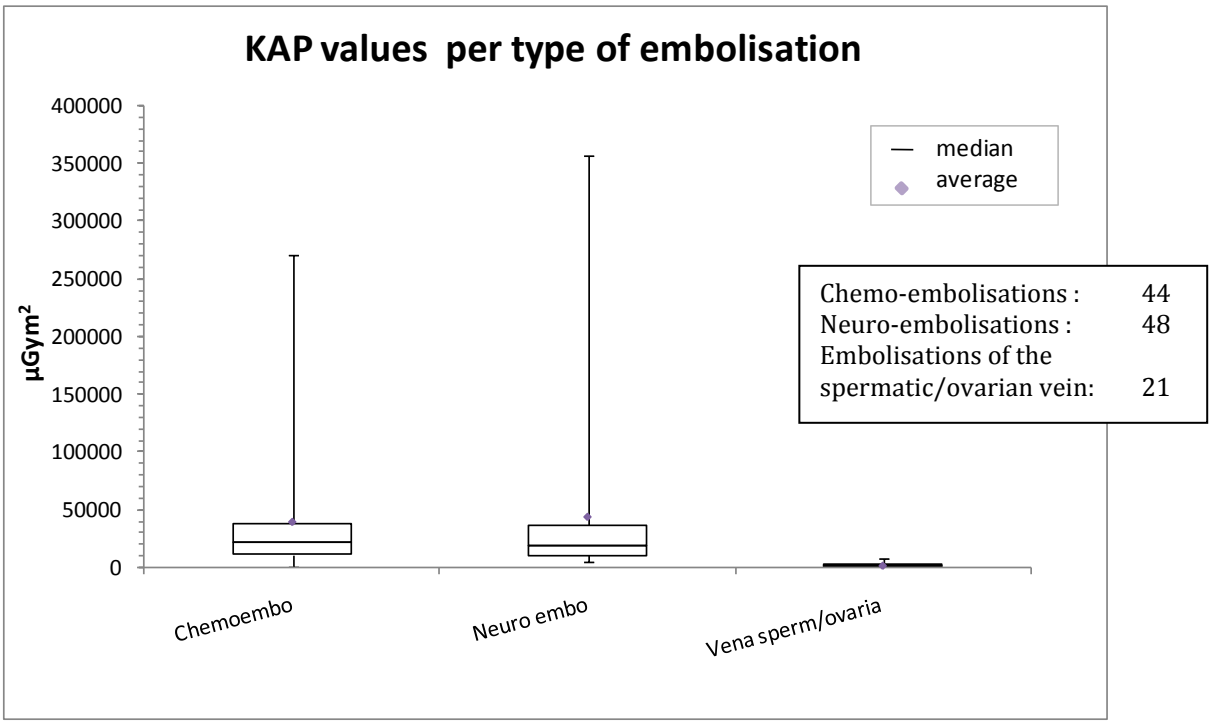
In the following graphs the KAP values per type of procedure is presented.



Graph 140: Box plots representing the KAP values per type of procedure (the statistics for the KAP values of the renal procedures are poor, as data from only 11 DSA R and 17 PTA R is available)

From the previous graphs the following comments can be drawn:

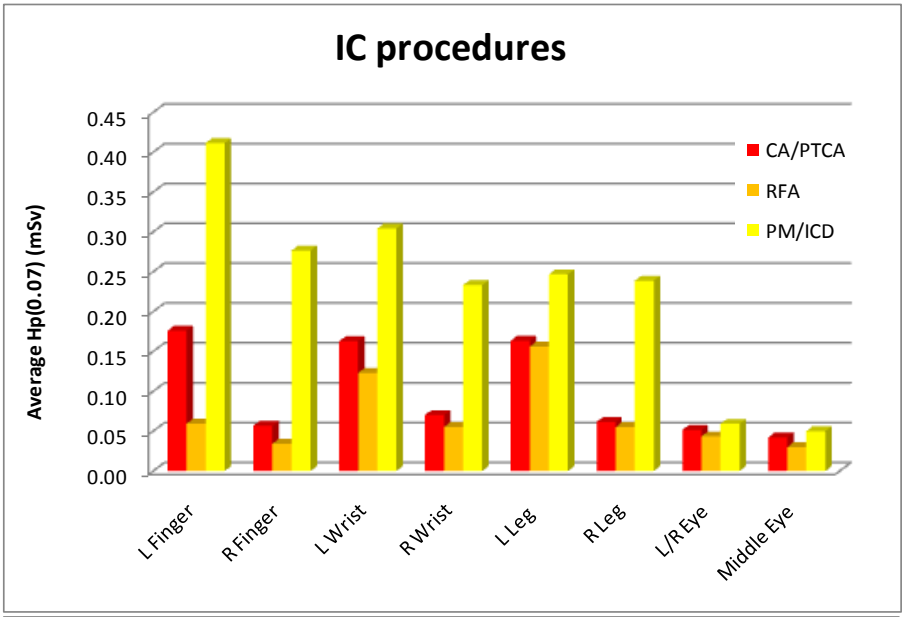
- The lowest KAP values are observed for the RF ablations, the PM/ICD implantations and the ERCP procedures. The reason for this is because during these procedures usually only fluoroscopy is used (RFA, PM/ICD) and/or only a few images are acquired (ERCP).
- Therapeutic procedures (Coronary angioplasties-PTCA, angioplasties of the lower limbs-PTA LL and the renal arteries-PTA R), as expected, have higher KAP values than the respective diagnostic ones.
- Finally, embolisation procedures are the most complicated ones and show the highest KAP values but also the largest variation in KAP. This is mainly due to the different types of embolisations that were monitored and also due to the variation in the complexity of such procedures. The most frequent embolisation procedures that were measured are shown on the following graph.

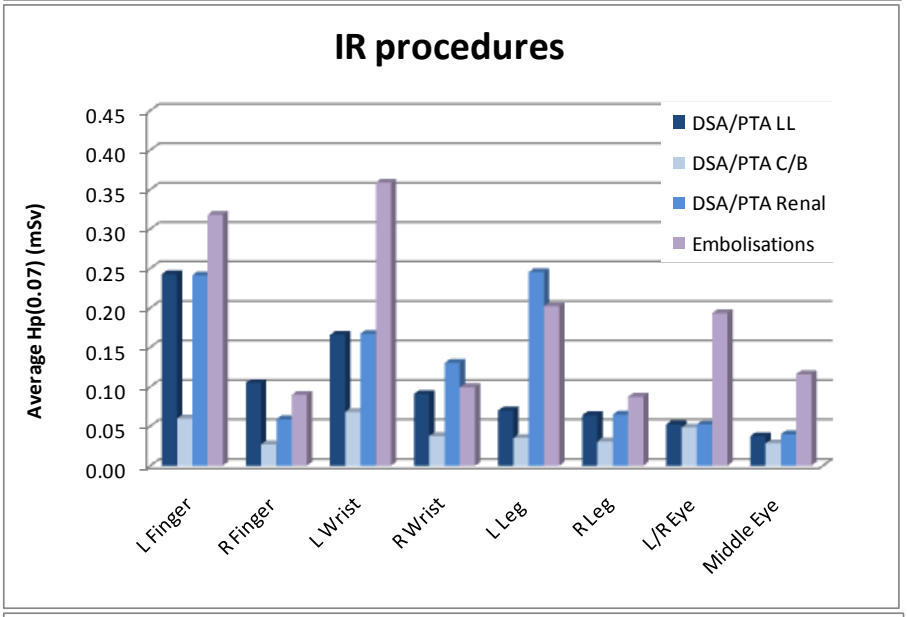


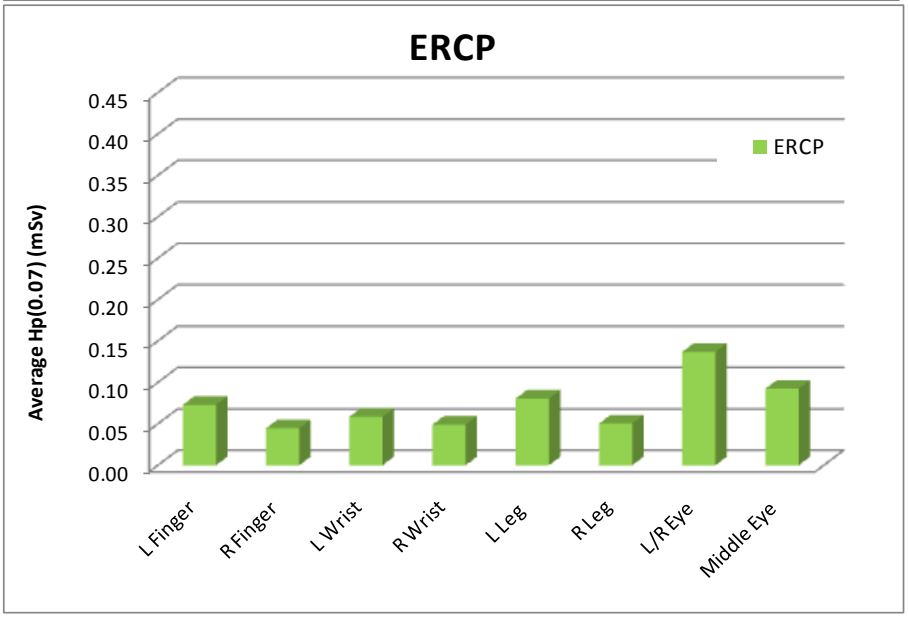
Graph 141: Box plots representing the KAP values for three types of embolisations.

Chemo- and neuro- embolisations present similar KAP values and significantly higher values compared to the embolisations of the spermatic/ovarian vein.

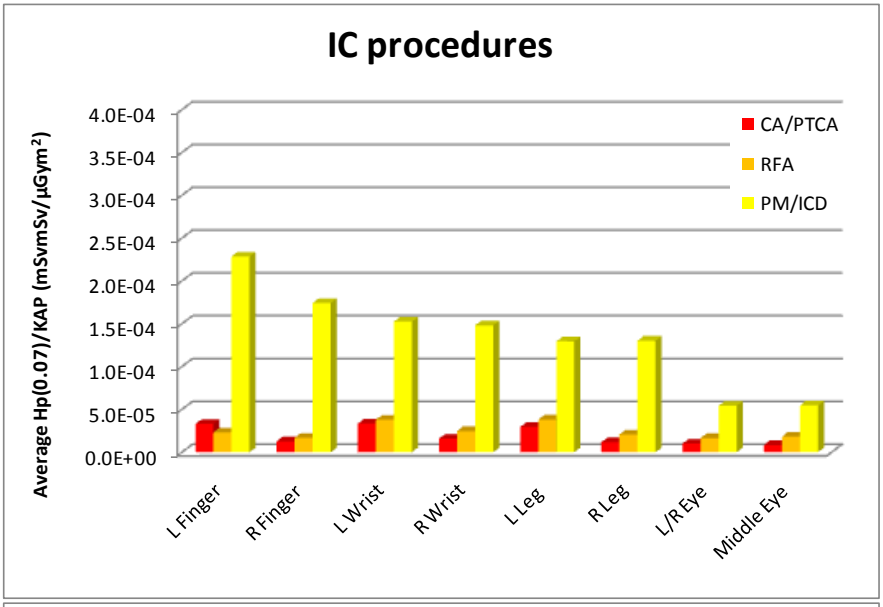
The mean doses per type of examination separated into the three above mentioned categories are presented in the following graphs.

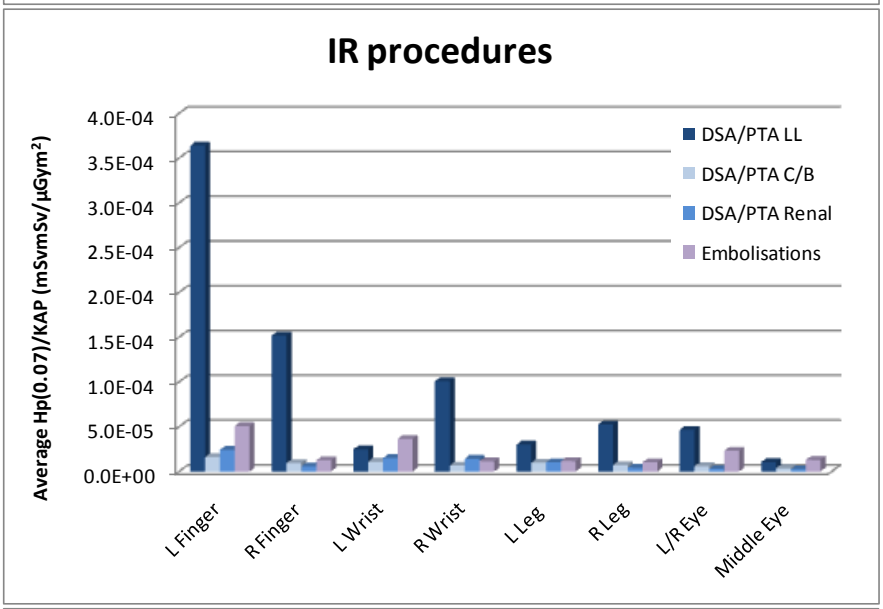


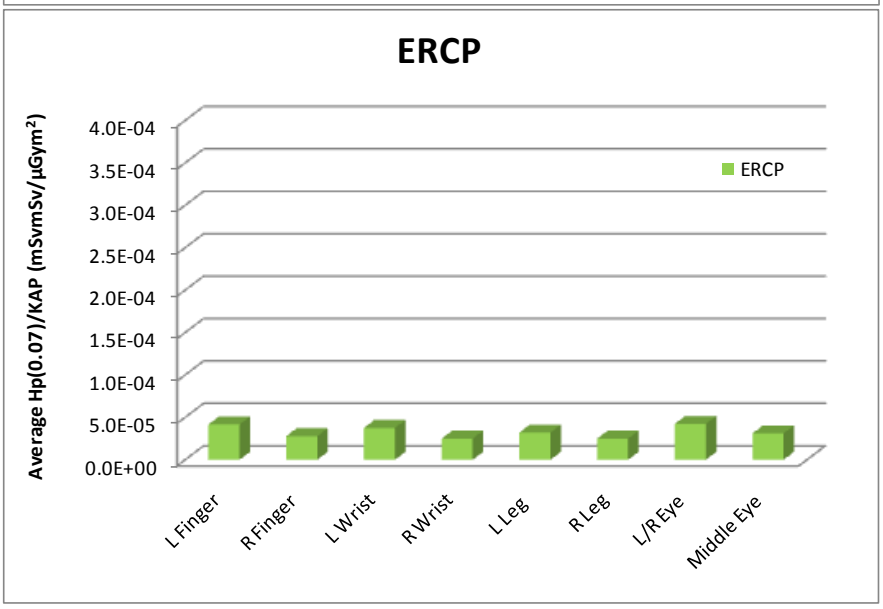




Graph 142: Mean doses per type of examination separated into 3 categories (IR, IC and ERCP).







Graph 143: Mean doses/KAP per type of examination separated into 3 categories (IR, IC and ERCP).

Among the types of cardiac procedures that were included in the measurement campaign, the doses to the operators are higher during PM and ICD implantations, even though the KAP values are relatively low since only fluoroscopy is used. During these procedures the operators work very close to the irradiating field and most of the time without any protective shield, as already mentioned in section 2.7.
Among the IR procedures special attention should be given to the embolisations, especially to the doses to the eye lenses. Operators are also significantly exposed during therapeutic procedures such as angioplasties of the lower limbs and the renal arteries. During cerebral procedures (not embolisations) the doses are relatively low since femoral access is usually used and the operator stands at a larger distance from the irradiated part of the patient's body compared to other procedures performed in the thoracic or abdominal area.
Finally, for ERCP procedures the doses are generally low. Special care should be taken regarding the use of a ceiling suspended shield, especially for the protection of the eyes, when overcouch irradiation is used.

3 Simulations

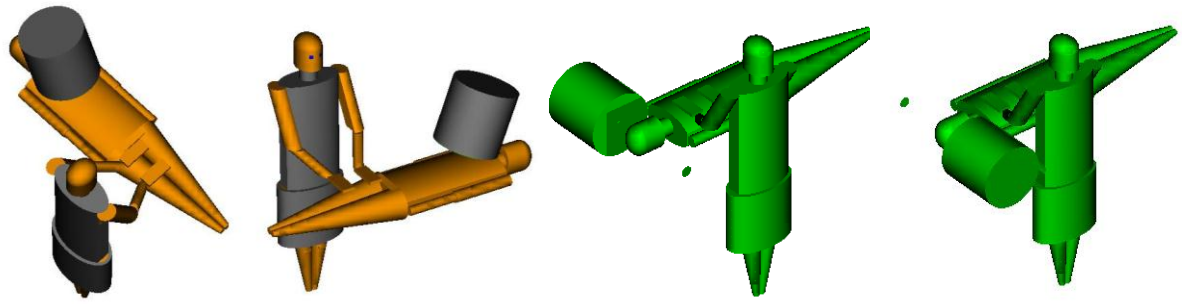
The goal of the simulation campaign is to investigate the parameters that may influence the extremity and eye lens doses such as kVp, filtration, field size, position of the operator and protective equipment. An advantage of this simulation campaign is that different parameters can be investigated systematically, independently from other parameters, which is not possible from the measurements.

3.1 Sensitivity study

Changing the aforementioned parameters one by one until all possible combinations are reached would have lead to an unrealistic number of simulations and would have increased the respective computing time enormously. Therefore, it was decided to investigate the influence of the beam quality with a more simplified geometry. In this geometry the patient is simulated by a simplified phantom and no phantom for the doctor is included in the input. For the different irradiated parts of the patient's body, different phantoms are used. For the head and neck irradiations, a head phantom is used (a cylinder of 20 cm diameter and 20 cm height, walls of PMMA with water inside) and for abdomen pelvis and lower limbs irradiations the ISO 4037 slab phantom is used. Extremity and eye lens doses are calculated on realistic positions around the "patient" phantom, using F5 tallies and the corresponding fluence to $H_p(0.07)$ and $H_p(3)$ (3) conversion coefficients. The image intensifier (II) is also included in the geometry. The tube voltage ranged from 60 to 110 kVp, filtration from 3 to 6 mm Al and from 0 to 0.9 mm Cu. The results of this sensitivity study are presented in the WP1 simulations intermediate report (4).

3.2 Detailed simulations

All the other parameters (field size, position of the operator and protective equipment) were studied using the detailed geometry with modified ORNL anthropomorphic phantoms for both patient and operator (fig.3).



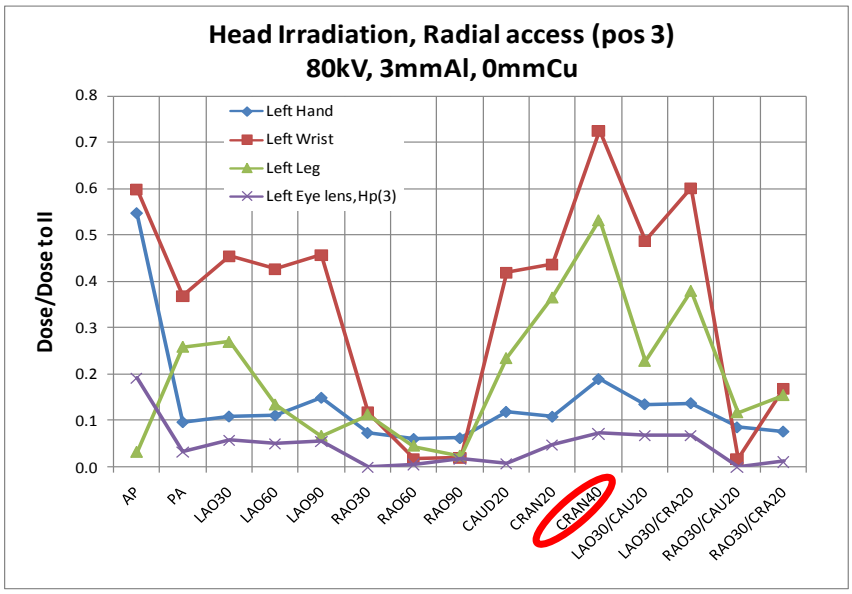
(a) (b) (c) (d)

Figure 3. Modified ORNL phantoms simulating the patient and the operator in positions that represent an interventional radiology procedure. An image intensifier and a KAP chamber were also included in the geometry. (a) Postero-anterior (PA) projection, (b) Cranial projection (CRAN), (c) Left Anterior Oblique 90º (LAO90º) projection, (d) Right Anterior Oblique 90º (RAO90º) projection

3.2.1 Most exposed area - Beam projections

Several beam orientations - projections that are used in clinical practice were selected. The effect of the beam projection to the left hand, wrist, leg and eye lens, for different irradiation conditions, without any protective shield, are presented in the following graphs.

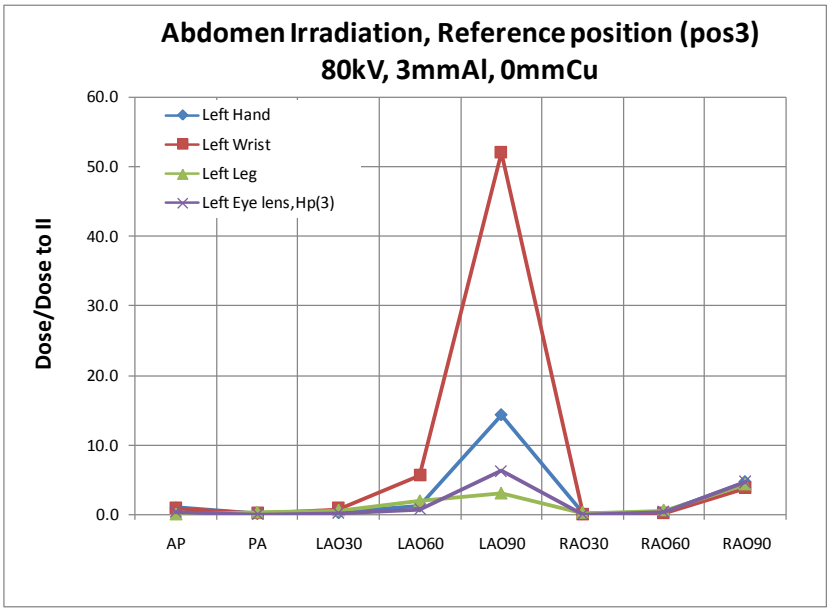
3.2.1.1 Head irradiation



Graph 144: The effect of the beam projection to the left hand, wrist, leg and eye lens, for head irradiation and the operator standing at the reference position (position 3 - 40 cm from irradiating field), corresponding to the level of the patient's arm, is presented. The field size in this case was 20 cm at the image intensifier.

For the specific geometry, in the case of head irradiation and the operator standing at the level of the patient's arm, the wrist is the most exposed location in most projections. The highest doses are obtained for the Cranial 40 (CRAN 40) projection (when the image intensifier is towards the patient's head). Next, the left oblique projections (tube positioned at the side of the operator and image intensifier towards the left side of the patient) give higher doses than the right oblique projections. Different results are found for overcouch irradiations (tube above the operating table) as will be discussed next.

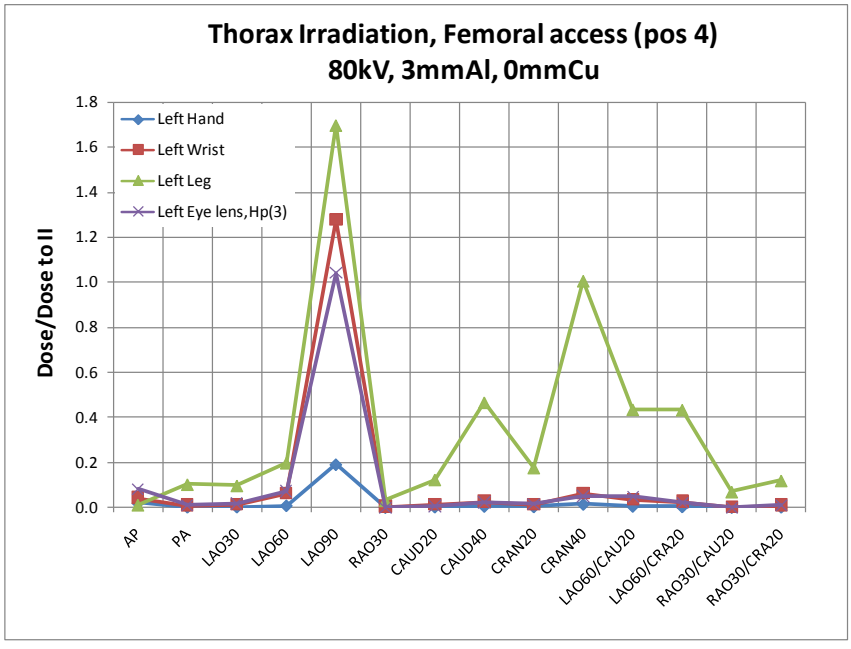
3.2.1.2 Abdomen irradiation



Graph 145: The effect of the beam projection to the left hand, wrist, leg and eye lens, for abdomen irradiation and the operator standing near the level of the patient's arm (40cm from irradiating field), is presented. The field size in this case was 40 cm at the image intensifier.

In the case of abdomen irradiation the field size was 40 cm, twice the size of the field used for head irradiation. This is why the hand and wrist are so much more exposed than the previous case. Cranial projections are not used in clinical practice so they were not included in the study. The LAO 90° projection shows the highest doses.

3.2.1.3 Thorax irradiation

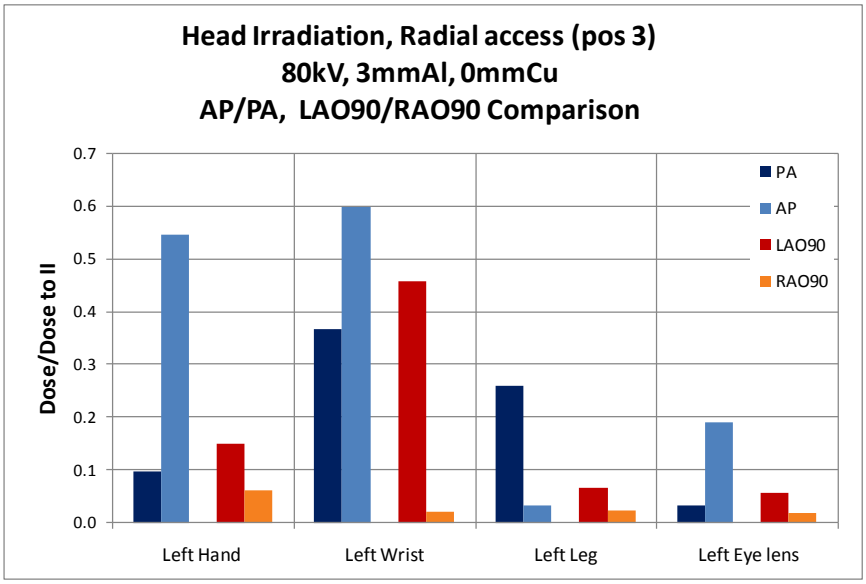


Graph 146: The effect of the beam projection to the left hand, wrist, leg and eye lens, for thorax irradiation and the operator standing at the level of the patient's femur (70cm from irradiating field), is presented. The field size in this case is 20cm at the image intensifier.

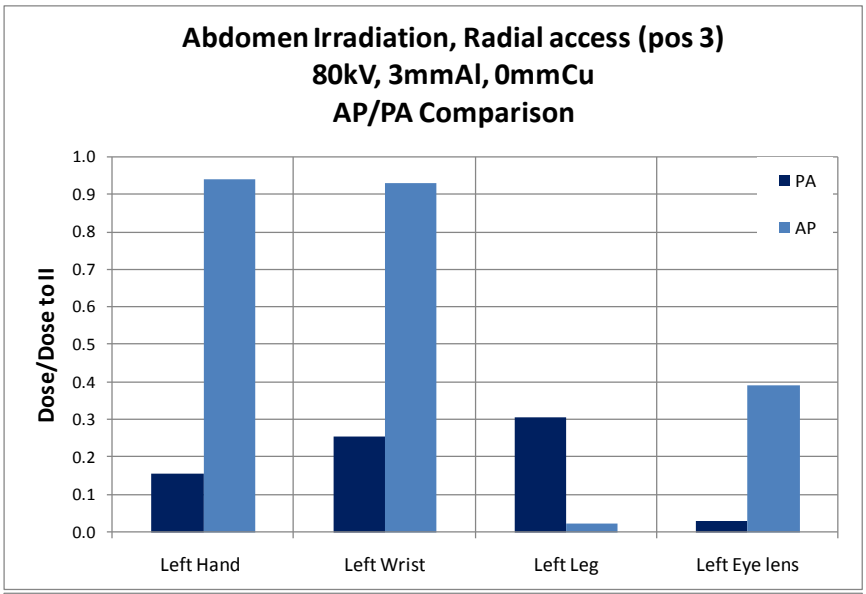
Finally for the thorax irradiation when the operator stands at the patient's femur, 70cm from the irradiating field, the legs are the most exposed for all the projections except the AP (the same is observed for head irradiation and PA projection – the other projections were not tested for

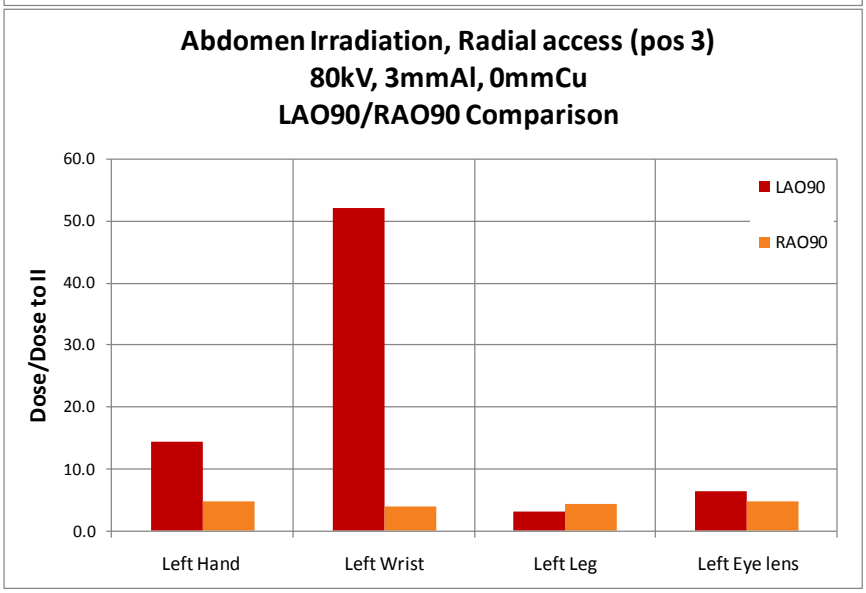
femoral access). Again the left oblique projections as well as the CRAN40º projectiongive the highest doses.

A comparison of PA and AP projections as well as a comparison of the two lateral ones (LAO 90º – figure 3a and RAO 90º figure 3b) are presented in the following graphs.

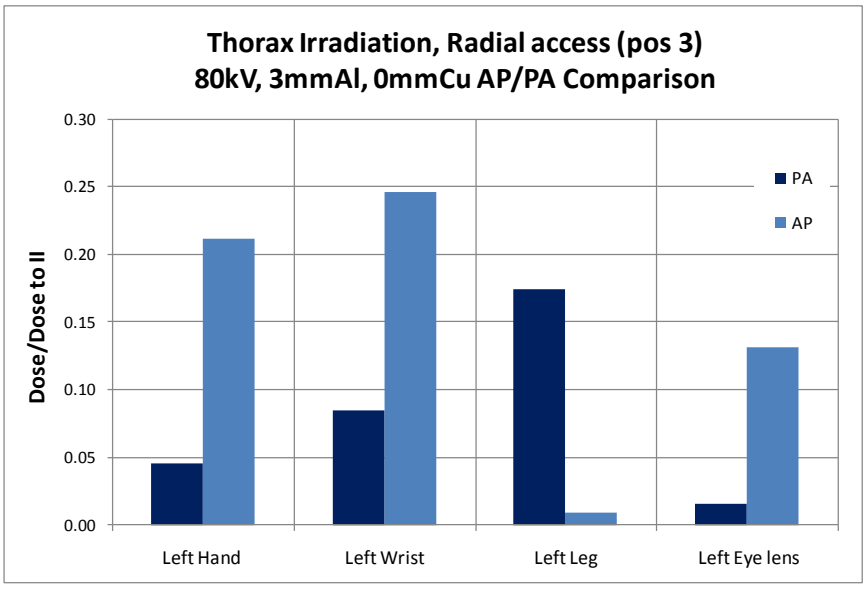


Head Irradiation	L hand	L wrist	L leg	L eye lens
Ratio (AP/PA)	5.63	1.62	0.13	5.77
Ratio (LAO90/RAO90)	2.39	22.09	2.72	3.08

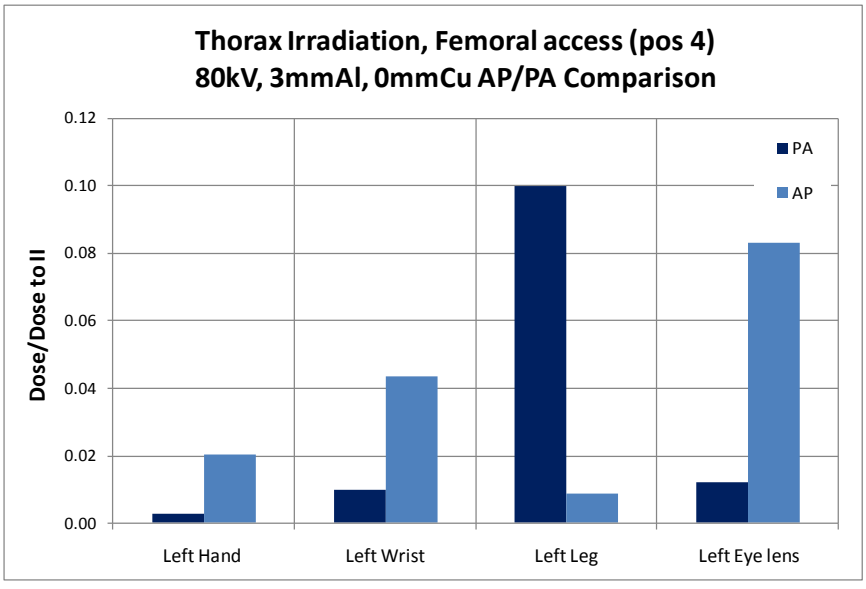




Abdomen Irradiation	L hand	L wrist	L leg	L eye lens
Ratio (AP/PA)	5.99	3.66	0.07	12.3
Ratio (LAO90/RAO90)	3.03	13.67	0.7	1.32



Thorax Irradiation	L hand	L wrist	L leg	L eye lens
Ratio (AP/PA)	4.61	2.9	0.05	8.1



Thorax Irradiation	L hand	L wrist	L leg	L eye lens
Ratio (AP/PA)	8.29	4.41	0.09	6.98

Graph 147: Comparison of overcouch (AP) – undercouch (PA) irradiation and comparison of lateral projections (LAO90º, RAO 90º) for head, abdomen and thorax irradiations. (RAO 90º is not usually used for thorax irradiation and was not included in the present study). The respective ratios are also presented.

In all cases the overcouch setup presents higher doses to all dosimetric locations except for the legs. The most significant dose reduction when using the undercouch setup is observed to the left hand and eye lens. As for the lateral projections, the LAO 90º presents higher doses to all locations, especially to the hands and wrists, compared to the opposite one (RAO 90º).

3.2.1.4 Conclusions

The left anterior oblique (LAO), where the operator stands at the side of the X-ray tube, and the cranial projections, where the image intensifier is towards the patient's head, generally give the highest doses.
When comparing the overcouch (AP) and undercouch (PA) irradiations, the undercouch irradiation is preferred as the doses were found up to 12 times lower to the eyes, 8 times to the hands and 4 times lower to the wrists, for the selected geometries.
For the lateral projections, the RAO90° is preferred (operator standing at the side of the image intensifier) as the doses were found up to 3 times lower to the eyes, 3 times to the hands and 22 times lower to the wrists compared to the LAO 90°, for the selected geometries.
Finally the left wrist was the most exposed in the case of head and abdomen irradiation with the operator standing close to the X-ray beam (radial access) and the leg was the most exposed for thorax irradiation when the operator was standing near the patient's femur (femoral access). No shields were present in those cases.

3.2.2 Protective equipment

One of the most important radiation protection measures is the use of protective shields during interventional radiology procedures. Monte Carlo simulations have been used to study the effect of the ceiling suspended shield, the lead glasses and the shield attached to the operating table, to the protection of the hands, wrists, eyes and legs.

3.2.2.1 Table and ceiling suspended shield

Three scenarios were selected to study the effect of the ceiling suspended shield to the protection of the eyes, hands and wrists of the operator, for a specific patient-operator setup (thorax and abdomen irradiation, femoral access). In the first scenario (A1) a curved ceiling suspended shield of 0.5 mm Pb is positioned very close to the patient and has a small tilt, as shown in figure 4. In the second case (A2) the same shield is (incorrectly) positioned 15cm above the patient (figure 5). The third scenario (B1) describes a rectangular ceiling shield positioned in touch with the patient, without tilt (figure 6). The effect of the table shield to the leg doses was studied at the same time.

Figure 4. Curved ceiling shield, 0.5 mm Pb, and operator standing at the level of the patient's femur. There is a very small gap between the patient and the ceiling shield (A1 case)

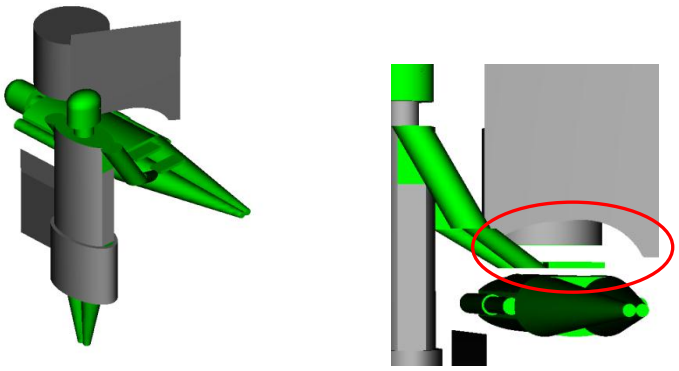


Figure 5. Curved ceiling shield 0.5 mm Pb, 15cm above the patient and operator standing at the level of the patient's femur. (A2 case)

Figure 6. Rectangular shield of same size as A1, 0.5 mm Pb, in contact with the patient and operator standing at the level of the patient's femur. (B1 case)

Finally, the effect of the lead glasses on the eye lens doses was also studied (fig 7).

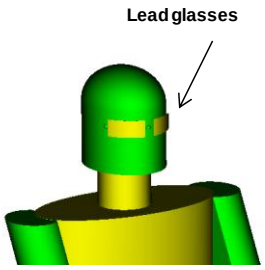
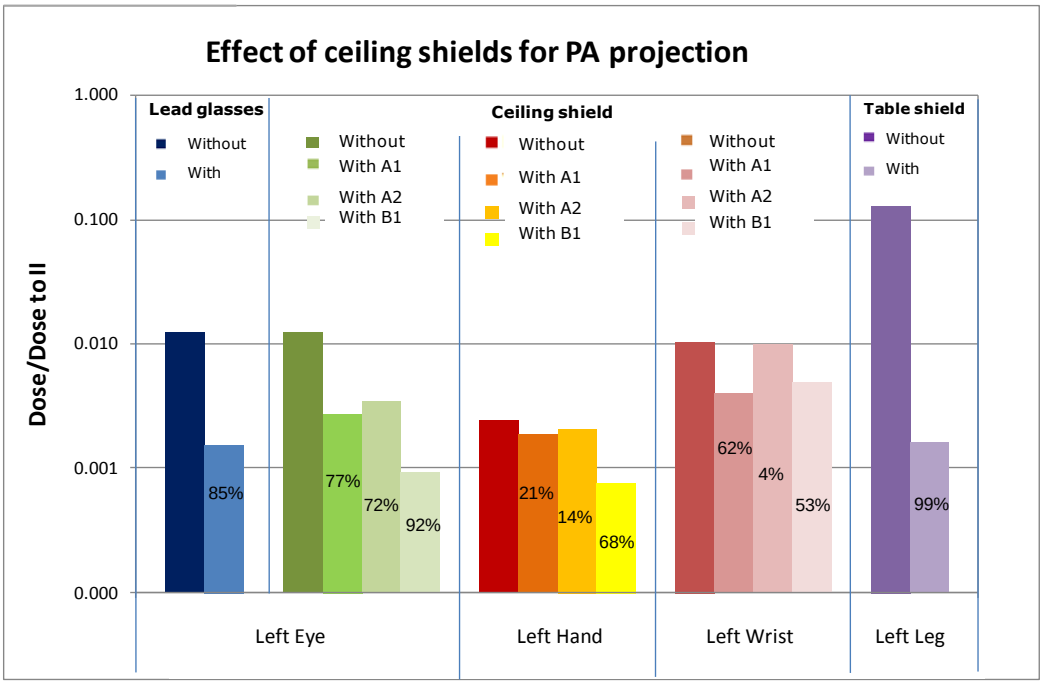


Figure 7. Lead glasses of 0.5 mm Pb.

These scenarios were studied for 4 different projections: PA, LAO 90º, RAO 30º and CRAN 40º.

1. PA projection

The effect of the different protective shields for thorax irradiation, 20 cm field diameter at the image intensifier (II) and PA projection are shown on the following graph. The distance of the operator from the centre of the field is 70 cm (femoral access).



Graph 148: The effect of the different protective shields for thorax irradiation, 20 cm field diameter at the image intensifier and PA projection, as well as the respective dose reduction is presented. The beam quality was HVL=2.7mmAl (70kVp, 3mmAl, 0mmCu).

In accordance with what was found for the measurements, for a tube below configuration, the effect of ceiling shield varies a lot with the shield's position and can have small effect to the dose on the hands and wrists if not properly positioned.

2. LAO 90º projection

For this projection, an additional setup (B2) is considered, where the ceiling shield is positioned on the left side of the operator (fig 8). The effectiveness of B1 and B2 case are examined. The specific cases were chosen for comparison because in clinical practice the ceiling shield is usually positioned at the beginning of the procedure and is not moved during the examination regardless the change of the beam projections. The results are shown on graph 149.

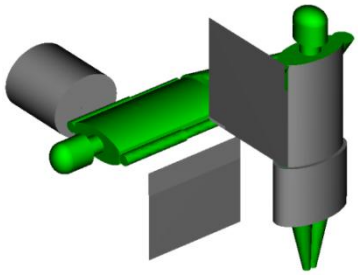
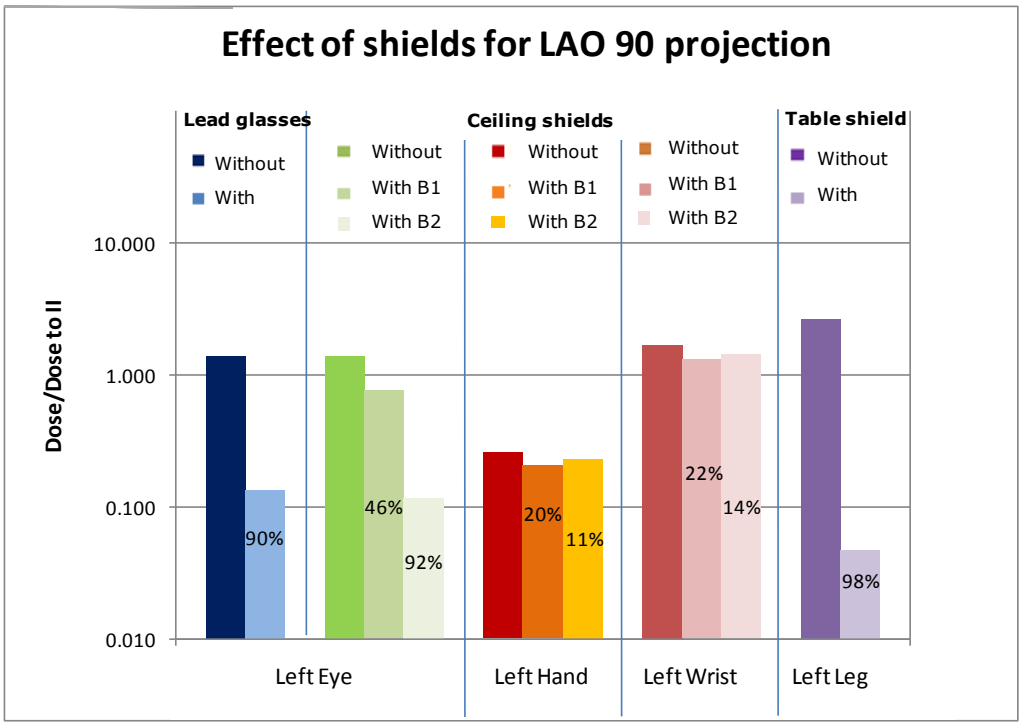


Figure 8. Rectangular shield same as B1 positioned on the left side of the operator when lateral projection LAO 90 is used and the operator is standing at the level of the patient's femur (B2 case)



Graph 149: The effect of the position of the B1 ceiling shield, for thorax irradiation and LAO90 projection and the respective dose reductions are presented.

For the left eye, we can observe that positioning the ceiling shield in this way for a lateral projection (or when biplane systems are used) has an important effect. Again the ceiling shield in these positions has small effect on the hand and wrist doses. In figure 9, a representation of the scattered radiation for different positions of the ceiling shield is presented.

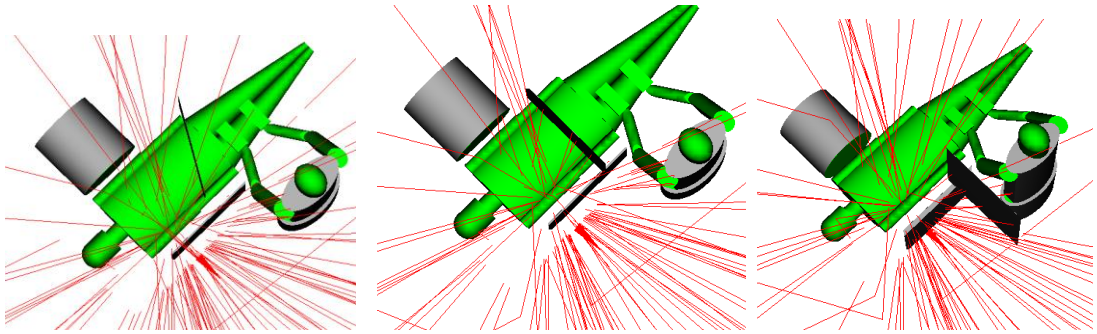


Figure 9. Representation of the scattered radiation and the effect of the different shields, A1, B1 and B2, for the lateral LAO 90º projection.

The results on the analysis of the protective equipment for thorax irradiation and all the studied projections, are shown on the following tables.

Table 8: The dose reduction to each dosimetric position due to the use of protective shields for thorax irradiation, is presented.

Projections	R eye lens, Hp(3)	L eye lens, Hp(3)	R Leg	L Leg
PA	15%	87%	98%	99%
LAO90	10%	90%	91%	98%
RAO30	31%	83%	97%	99%
CRAN40	23%	87%	83%	97%

Table shield and lead glasses

Projections	R eye lens, Hp(3)	L eye lens, Hp(3)	R Hand	L Hand	R Wrist	L Wrist
PA	83%	77%	49%	21%	16%	61%
LAO90	25%	22%	19%	17%	24%	39%
RAO30	85%	81%	41%	22%	42%	73%
CRAN40	83%	83%	44%	22%	13%	43%

A1 scenario

Projections	R eye lens, Hp(3)	L eye lens, Hp(3)	R Hand	L Hand	R Wrist	L Wrist
PA	73%	72%	42%	14%	5%	4%
LAO90	19%	22%	19%	16%	9%	14%
RAO30	39%	38%	31%	8%	5%	2%
CRAN40	37%	42%	36%	20%	11%	29%

A2 scenario

Projections	R eye lens, Hp(3)	L eye lens, Hp(3)	R Hand	L Hand	R Wrist	L Wrist
PA	93%	92%	66%	68%	19%	53%
LAO90	64%	46%	27%	20%	12%	22%
RAO30	87%	86%	45%	42%	14%	45%
CRAN40	86%	88%	46%	33%	16%	43%

B1 scenario

Projections	R eye lens, Hp(3)	L eye lens, Hp(3)	R Hand	L Hand	R Wrist	L Wrist
LAO90	93%	92%	66%	68%	19%	53%

B2 scenario

Note: The results refer to the specific simulated model and setup; nevertheless, they are indicative of the effectiveness of the lead shields and the importance of their proper use.

- The table shield is very effective for protecting the legs for all projections tested.
- For the specific geometry (operator standing 70 cm from the irradiating field), the lead glasses protect very well the left eye but have small effect on the right eye as the scattered radiation reaching this area comes from the side of the operator which is not protected.
- A1 ceiling shield is very effective for the protection of the eyes, except for the lateral LAO 90° projection. The dose to the hands is reduced 17-49% and to the wrists 13-73% depending on the projection. The left hand is generally not well protected because the ceiling shield is not touching with the patient.
- Moving up the ceiling shield 15cm (case A2) compared to the A1 case, the following conclusions can be drawn.
    - The A2 ceiling shield is less effective than the previous case (A1), especially to the hands and wrists, which are practically not protected (fig. 5).

- The dose reduction to the eyes is similar in the two cases for PA and LAO90 projections; however, for the RAO30 and CRAN40 projections A2 case is again less effective.

- B1 ceiling shield is generally more effective than A1 shield. It is very effective for the eyes and it protects better the hands as it is touching the patient compared to the A1 case where there is a small gap between the shield and the patient (fig. 4,6).

- B2 ceiling shield is more effective than all previous shields for the LAO 90° lateral projection.

The results on the analysis of the protective equipment for abdomen irradiation and all the studied projections are shown on the following tables. The distance of the operator from the centre of the field is now 33cm (femoral access) and the field size is 40cm at the II.

Table 9: The dose reduction to each dosimetric position due to the use of protective shields for abdomen irradiation is presented.

Table shield

Projections	R Leg	L Leg
PA	97%	99%
LAO90	90%	98%
RAO30	92%	97%
CRAN40	81%	97%

A1 scenario

Projections	R eye lens, Hp(3)	L eye lens, Hp(3)	R Hand	L Hand	R Wrist	L Wrist
PA	78%	64%	41%	28%	28%	66%
LAO90	44%	31%	23%	20%	54%	67%
RAO30	96%	96%	35%	16%	38%	69%
CRAN40	72%	66%	31%	17%	21%	39%

A2 scenario

Projections	R eye lens, Hp(3)	L eye lens, Hp(3)	R Hand	L Hand	R Wrist	L Wrist
PA	65%	55%	23%	5%	9%	6%
LAO90	37%	29%	18%	14%	15%	14%
RAO30	90%	93%	19%	4%	14%	4%
CRAN40	72%	66%	31%	17%	21%	39%

B1 scenario

Projections	R eye lens, Hp(3)	L eye lens, Hp(3)	R Hand	L Hand	R Wrist	L Wrist
PA	95%	94%	53%	55%	20%	54%
LAO90	85%	70%	29%	30%	22%	47%
RAO30	96%	97%	35%	62%	38%	62%
CRAN40	90%	91%	44%	40%	18%	30%

B2 scenario

Projections	R eye lens, Hp(3)	L eye lens, Hp(3)	R Hand	L Hand	R Wrist	L Wrist
LAO90	62%	78%	15%	11%	14%	12%

Note: Again the results refer to the specific simulated model and setup.

- Also for this scenario the table shield is very effective for protecting the legs all projections tested.

- Using the A1 shield the dose to the hands is reduced 16-41% and the dose to the wrists 21-69%, depending on the projection. The lowest dose reduction to the eyes is observed for the LAO 90^{o} projection and to the hands and wrists for the CRAN 40^{o} projection. The left hand is generally not well protected because it is very close to the irradiating field and the ceiling shield is not touching the patient as in the B1 case.

- A2 ceiling shield is less effective than the previous case (A1), especially to the hands and wrists, which are practically not protected. For the eyes the dose reduction is similar for the A1 and A2 case.

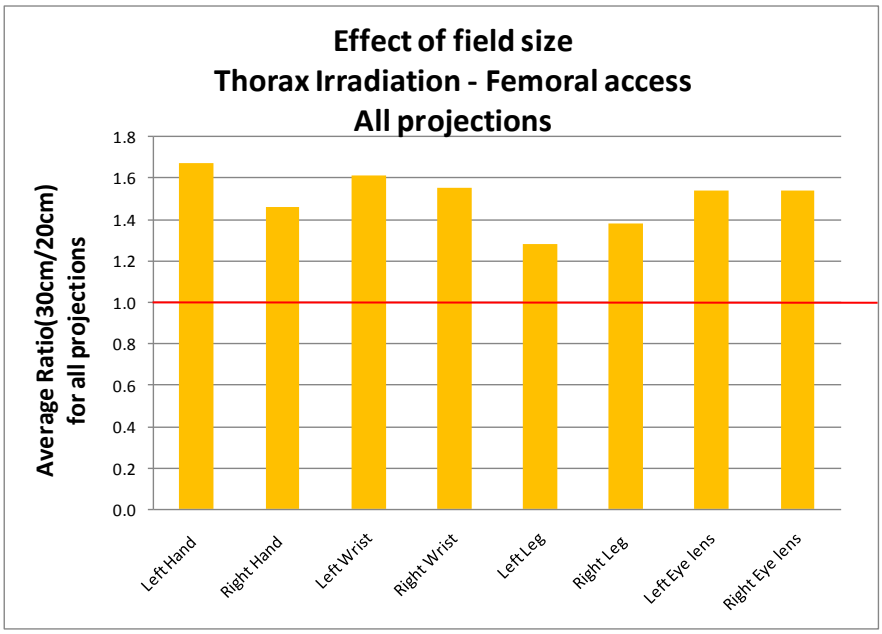
- B1 ceiling shield is very effective for the eyes and it protects the hands better than the A1 shield, as previously mentioned.

3.2.2.2 Conclusions

The table shield is very effective for the protection of the legs and reduces the dose from 81% to 97% for the geometries and setups that were tested.
The lead glasses, for the specific geometry that was examined, are very effective for the protection of the eye lens which is closer to the X-ray tube (dose reduction up to 90%) but was not so effective for the other eye lens. In practice, lead glasses that cover well the eyes and also have lateral protection are advised.
A ceiling suspended shield is also very effective for the protection of the eyes; its use is essential especially when lead glasses are not available or cannot be worn for practical reasons. This type of shield also provides protection to the hands (up to 68%) and wrists (up to 73%).
The comparison of A1, A2 and B1 cases shows how important it is to correctly place the ceiling shield. Even a small gap between the patient and the shield reduces the effectiveness of the shield to the hands. For this reason a shield with lead stripes attached at the bottom so that it touches the patient is advised.
For the lateral projections the eyes are better protected when the shield is positioned more to the side of the operator (case B2) and not just above the patient (the dose reduction to the left and right eye lens was 92 and 93% for the B2 case compared to 46 and 64% for the B1 case). In practice, a second shield is advised especially when biplane technique is used, so that the operator is protected from both X-ray tubes.

3.2.3 Field size

The effect of the field size was studied for the case of thorax irradiation when the operator stands at the position of the patient's femur. Two field sizes 30 cm and 20 cm, for a beam quality of HVL=3.5mmAl (90kVp, 3mmAl, 0mmCu), were tested and the respective ratios are presented in the following graph.



Graph 150: The average ratio of the doses calculated for two field sizes 30cm and 20cm, for all projections, thorax irradiation and femoral access are presented.

The dose reduction when a more collimated field is used and the operator stands closer to the irradiated part of the patient was also tested.

Table 10. The ratios of the doses calculated for two field sizes 30 cm and 20 cm, only for the PA projection for radial access are presented. The respective ratios for femoral access are also shown for comparison.

30cm/20cm	L Hand	R Hand	L Wrist	R Wrist	L Leg	R Leg	L Eye lens	R Eye lens
PA (Radial)	10.4	6.2	3.2	2.7	1.3	1.4	1.2	1.2

30cm/20cm	L Hand	R Hand	L Wrist	R Wrist	L Leg	R Leg	L Eye lens	R Eye lens
PA (Femoral)	1.4	1.2	1.3	1.2	1.1	1	1.4	1.2

3.2.3.1 Conclusions

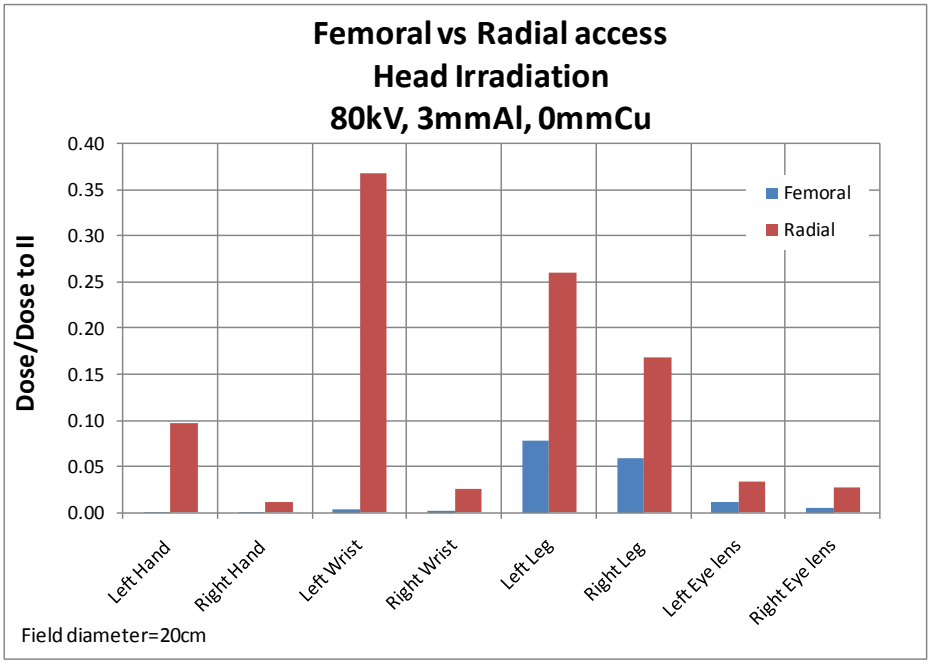
For all monitored positions the doses are higher when a larger field size is used. More scattered radiation is produced if a larger part of the patient is irradiated. The largest dose increase when larger fields are used is observed to the left hand which is closest to the irradiating field. The dose to the eye lenses is also significantly influenced by the field size. The dose to the legs seems to be the less affected in this case.
Finally, the dose reduction to the hands and wrists because of a more collimated beam becomes much more important when the operator stands closer to the irradiating field.

3.2.4 Access of the catheter - position of the doctor

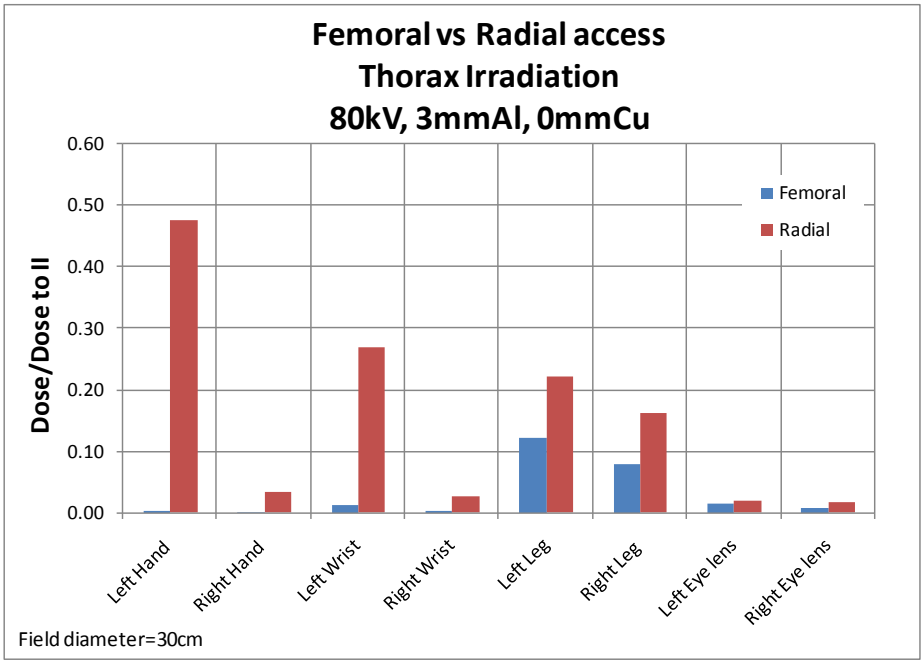
The effect of the point of access of the catheter and the position of the doctor was studied for the following cases:

- Head irradiation (field Ø=20 cm),
  femoral access (field-operator distance x=110 cm)
  radial access (field-operator distance x=40 cm)
  PA projection
  } dx=70 cm
- Thorax irradiation (field Ø=30 cm),
  femoral access (field-operator distance x=70 cm)
  radial access (field-operator distance x=30 cm)
  PA projection
  } dx=40 cm

No protective shields were used in the previous cases.



Head Irradiation	L Hand	R Hand	L Wrist	R Wrist	L Leg	R Leg	L Eye lens, Hp(3)	R Eye lens, Hp(3)
Ratio (R/F)	102.9	13.1	109.8	11.7	3.3	2.8	2.7	4.7



Thorax Irradiation	L Hand	R Hand	L Wrist	R Wrist	L Leg	R Leg	L Eye lens, Hp(3)	R Eye lens, Hp(3)
Ratio (R/F)	132.1	18.5	19.4	6.8	1.8	2.0	1.2	1.8

Graph 151: The doses to the different anatomic locations using femoral and radial access technique and the respective ratios (radial/femoral) are presented for head and thorax irradiation separately.

3.2.4.1 Conclusions

In both cases the hands and wrists are the most affected when approaching the irradiation field. Moreover, in the case of femoral access the legs are the most exposed for both head and thorax

irradiation. The absolute values of the ratios cannot be compared as the irradiation conditions are different in the two cases.

4 Comparison of measurements and simulations

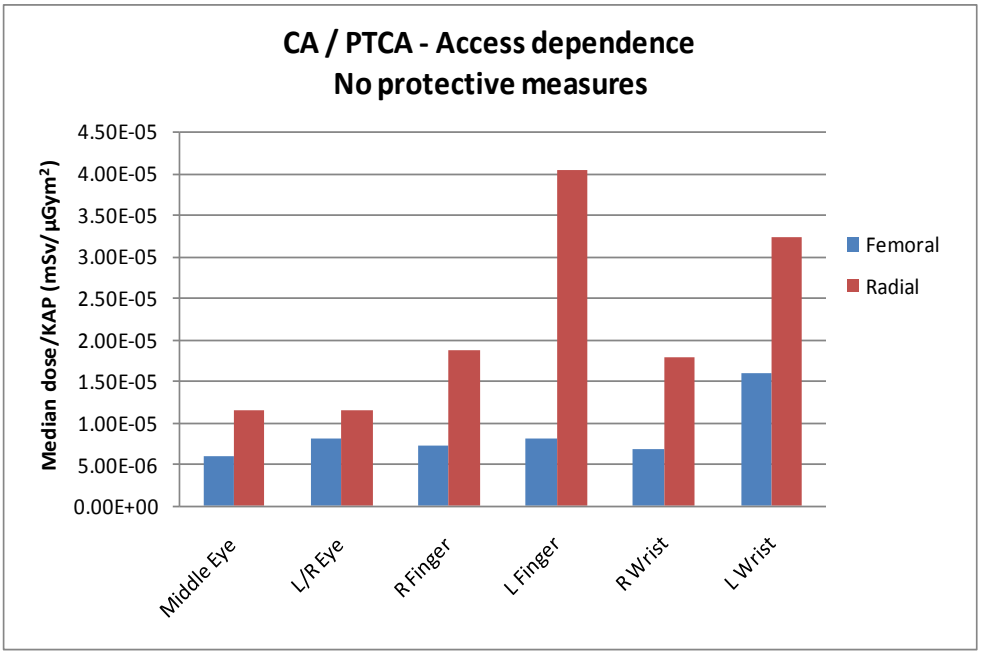
4.1 Access of the catheter

The case of CA/PTCA without the use of protective equipment was examined and compared to the results from thorax irradiation simulations, again without shielding. For femoral access there were 51 measurements without the ceiling suspended shield and 29 cases without the table shield. For radial access 30 cases had no ceiling suspended shield and for only one case the table shield was not present. Therefore, the legs were not included in the comparison. Undercouch irradiation was used in all cases.

Some differences between measurements and simulations are the following:

- only 4 projections were examined for the simulations (PA, LAO 90º, RAO 30º, CRAN 40º), however many projections are used during CA/PTCA procedures. The average ratios (radial/femoral) of the 4 projections in the calculations were used for the comparison.
- only one beam quality - 70kVp, 3mmAl, 0mmCu (HVL=2.7mmAL) – and one field size (20 cm diameter at the II) were used for the simulations.

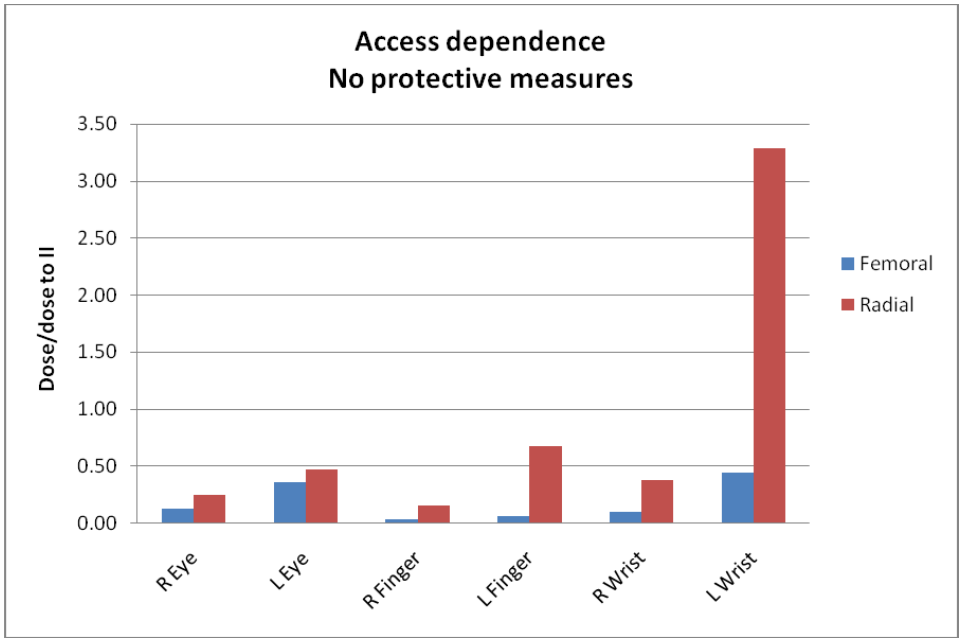
The results from the measurements are presented on the following graph.



	M Eye	L/R Eye	R Finger	L Finger	R Wrist	L Wrist
Ratio (R/F)	1.91	1.41	2.56	4.96	2.63	2.01

Graph 152: The median doses/KAP to the different anatomic locations using femoral and radial access technique and the respective ratios (radial/femoral) are presented for the case of CA/PTCA examinations.

The respective results from the Monte Carlo calculations are presented on the following graph.



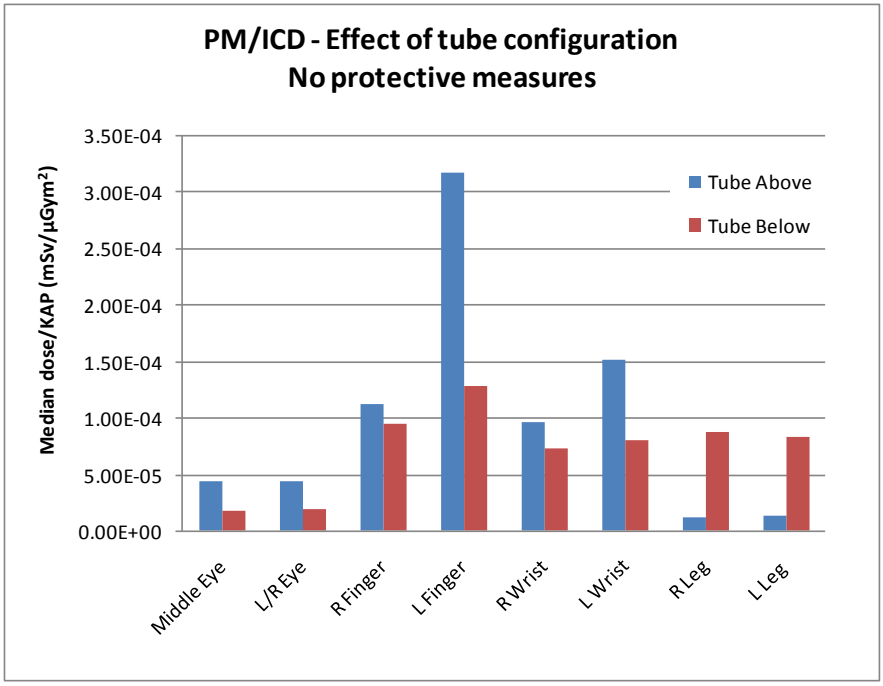
	R eye lens, Hp(3)	L eye lens, Hp(3)	R Finger	L Finger	R Wrist	L Wrist
Ratio (R/F) Average of 4 projections	1.98	1.31	3.93	9.78	3.71	7.39

Graph 153: The doses to the different anatomic locations for femoral and radial access and the average ratios (radial/femoral) for the 4 projections (PA, LAO 90º, RAO 30º, CRAN 40º) are presented.

Taking into account the limitations mentioned above, the same trends are observed comparing the results from measurements and simulations and the ratios (radial/femoral) are comparable in the two cases. The effect of the access position to the doses is more important on the fingers and wrists in both cases. The eyes are less affected because, even though the operator stands closer to the primary beam when using radial access, the image intensifier sometimes plays the role of shielding (depending on the projection).

4.2 Tube configuration

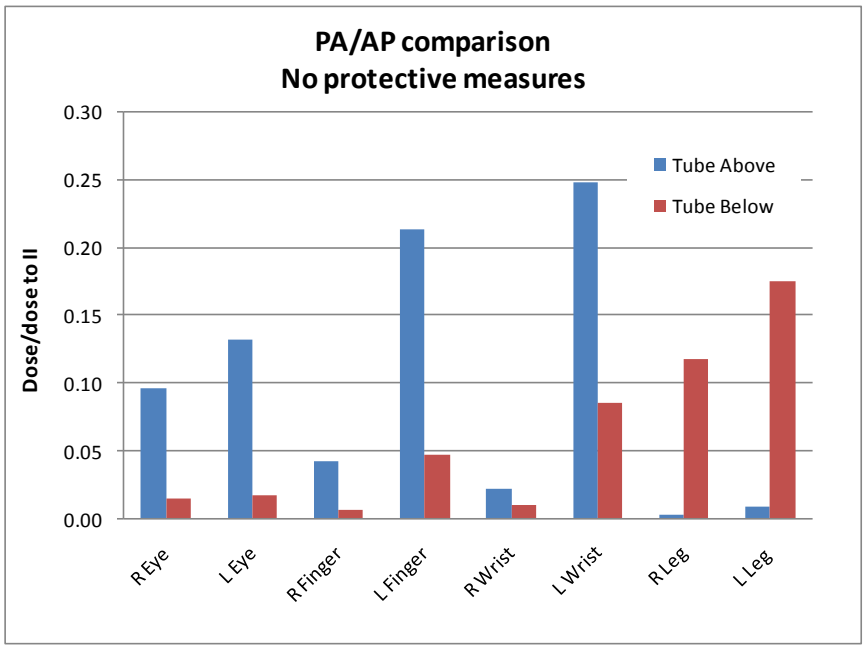
The results from PM/ICD implantations (without shielding) will be used because the projection doesn't change during these procedures. For undercouch irradiation 165 measurements had no ceiling suspended shield and 121 had no table shield. For overcouch irradiations only 10 cases had neither ceiling nor table shield.
The results from the measurements are presented on the following graph.



	M Eye	L/R Eye	R Finger	L Finger	R Wrist	L Wrist	R Leg	L Leg
Ratio (A/B)	2.39	2.33	1.18	2.49	1.32	1.87	0.14	0.16

Graph 154: The measured median doses/KAP to the different anatomic locations for overcouch (above) and undercouch (below) irradiation and the respective ratios (above/below) are presented for the case of pacemaker and cardiac defibrillator implantations (PM/ICD).

For the simulations the case of thorax irradiation and the operator is standing at 30 cm from the centre of the field (20 cm diameter at the II) was selected. The beam quality was HVL=3.1 mmAl (80 kVp, 3 mmAl, 0 mmCu). The results from the Monte Carlo calculations are presented on the following graph.



	R eye lens, Hp(3)	L eye lens, Hp(3)	R Finger	L Finger	R Wrist	L Wrist	R Leg	L Leg
Ratio (A/B)	6.66	8.06	7.57	4.61	2.30	2.90	0.02	0.05

Graph 155: The doses to the different anatomic locations for overcouch (AP) and undercouch (PA) irradiation and the respective ratios (above/below) are presented.

The doses are significantly lower to the eyes, hands and wrists for the undercouch irradiations in both cases. The absolute values of the ratios cannot be compared as there are several differences between the simulations and the measurements. Moreover there were only 10 measurements using overcouch irradiation, so the calculated ratios from the measurements are not so reliable.

5 Extrapolation to annual doses

The annual dose limit for deterministic effects to the skin is set to 500 mSv averaged over 1cm^2 area of skin regardless of the area exposed. The annual dose limit for deterministic effects to the eye lens is set to 150 mSv.

Within the ORAMED project an overview of the annual doses has also been attempted. The measurements that were performed during the measurement campaign for each operator were used. The number of procedures that each operator performs in annual basis was estimated and then was used for the extrapolation. The estimation was done either by the operator himself or using the log book of each department. The calculation was done by multiplying the average dose[2] obtained for a certain procedure with the respective workload (number of procedures) of one year. In cases where the operator performs other kind of procedures than those monitored during the ORAMED project, it is mentioned in the calculation procedure, but it is not possible to take it into account for the estimation of the annual limit. Table 1, 2 and 3 in Appendix 2 contain all the collected data that were used for the estimation of the annual doses, as well as for the percentage of the respective dose limit. The following Table 11 contains the data for the operators that exceed the 50 mSv for the extremities (fingers, wrists and legs) and 15 mSv for the eyes. These values are the 1/10th of the respective dose limit, which is actually required for dose monitoring. Four dosimetric locations were used: fingers, wrists, eyes and legs. In the Appendix 2, the graphs with the annual doses per operator are also included.

[2] The dose that was used for the calculation was the maximum value of the two average doses calculated for the left and right positions (eyes, fingers, wrists and legs)

In ERCP procedures the doses are generally very low when compared with the annual dose limits. Maximum values of annual doses of 68 mSv at the fingers are obtained.

For the IC sector the doses from the PM procedures are usually much higher than the doses from the RF ablations and CA & PTCA procedures. In general, the hands are very close to the X-ray beam for PMs. Moreover, it was observed that for these procedures protective equipment is hardly used, while for CA & PTCA and RF ablations, the use of protective equipment becomes really common. When the shields are properly used, then the doses for PMs can also be very low.

Table 11: Table with the operators that exceed the 1/10th of the annual limit for the extremities and eyes

				Max <Dose> per proc (mSv)				Annual Dose (mSv)			
Operator	Procedure	# Procedures	# Measmts	*Finger m*	*Wrist m*	*Leg m*	*Eye m*	*Finger*	*Wrist*	*Leg*	*Eye*
B11	CA&PTCA	255	4	0,16	0,16	0,32	0,04			81	
B16	PM, ICD, RF Ablations	212	5	4,14	2,01	2,33	1,38	512	264	345	129
B17	CA&PTCA	233	5	0,31	0,41	0,28	0,12	71	95	66	28
B3	ERCP	100	7	0,68	0,42	0,01	0,50	68			50
F14	PM&ICD	144	3	0,18	0,24	0,46	0,01			66	
A15	CA&PTCA	750	4	0,07	0,15	0,07	0,05	56	112	56	40
A19	CA&PTCA	600	1	0,09	0,28	0,19	0,02	52	170	115	
A17	Radiology	550	12	0,59	0,31	0,68	0,14	147	69	124	22
A10	Radiology	484	5	0,72	0,50	3,97	0,15	109	75	655	15
E15	Radiology	149	9	4,35	1,84	0,19	0,49	648	275	28	72
E3	CA&PTCA	1157	4	0,08	0,09	0,22	0,06	95	102	256	69
E10	CA&PTCA	998	4	0,02	0,04	0,12	0,05			121	46
E12	CA&PTCA	1067	1	0,01	0,01	0,10	0,01			102	
K1	vertebro/kypho	176	8	2,92	1,45	0,08	0,36	514	256		64
G4	CA&PTCA	904	3	0,05	0,05	0,03	0,03				26
G5	PM, ICD, RF Ablations	374	8	0,66	0,63	0,36	0,20	123	117	68	38
G6	PM, ICD, RF Ablations	275	9	1,59	1,06	0,41	0,32	142	102	37	32
OP6	Embolisation	0	2	0,05	0,02	0,02	0,02		105	52	
OP9	Radiology	357	4	0,76	0,70	0,25	0,43	52	60		31
OP15	PM/ICD	400	6	0,53	0,00	0,25	0,08	213		100	31
OP33	Radiology	454	5	0,02	0,03	0,16	0,03			74	
OP34	Radiology	323	12	0,94	0,72	0,48	0,26	62	50	35	20
OP35	Radiology	212	26	1,77	2,38	0,65	1,17	137	148	43	70
OP40	CA PTCA	630	9	0,02	0,03	0,06	0,02				
OP41	Embolisation (Aneurysm+AVM)	90	8	0,00	0,62	0,25	0,95		56		85
MK	CA PTCA	500	3	0,05	0,04	0,01	0,01				
TJ	CA PTCA	1000	3	0,11	0,11	0,01	0,03	114	107		27
ZK	Radiology	201	20	0,70	1,44	0,11	0,14	40	74	5	9
SMU1	CA PTCA	500	0	0,34	0,26	0,07	0,04	198	187		30
SMU2	DSA PTA LL	500	0	0,08	0,08	0,10	0,01	89	73	221	

In the IR sector there are cases, like complicated embolization procedures, where the hands need to be very close to the beam and for this reason the doses are really high. For most of the procedures monitored during this project the doses are low; however annual doses of 513 mSv at fingers were recorded.

From the graphs in Appendix 2 and the Table 11, it is seen that there are a few cases where the extremity annual limits are exceeded. These values may have been underestimated given the radiologists' diversity of work and the lack of information, sometimes, on their workload.

For the leg doses, though they are generally low, there are cases where the operator or assistant is not properly shielded by the table shield and for this reason the leg doses are considerably high (for example operator OP15, in the Appendix 2).

Finally, there are no cases where the eye dose limits are exceeded. However, there are cases with considerably high values of eye lens doses which is usually due to the improper use of ceiling or lateral shield in biplane technique. This might cause problems if there is a reduction on the eye limit in the future.

6 Recommendations

The measurement and simulation campaign performed within the ORAMED project revealed the large variability of practices followed in different hospitals. As a consequence, the measured

doses, even for one specific procedure, vary significantly from one room to another. The various parameters which a priori could influence the doses were studied and analysed through the measurements and simulations and the following recommendations were drawn. It is important to note that some of the proposed guidelines are bound by restrictions (clinical quality or financial reasons) and cannot be easily changed. However, some of them are easily adjustable and can improve significantly the protection of the medical staff.

- The ceiling suspended shield should be placed just above the patient; the operator should stand well behind it. When the ceiling shield is properly used there is a significant reduction of the eye dose (2-7 times), especially in cases where the tube is placed above the operating table.
- When ceiling suspended shield is not available protective glasses can be used; Most effective are the ones with the lateral shielding.
- The table shield should be always properly adjusted to protect both legs. The proper positioning of the table shield is very important for the assistant as well, who, in many cases, stands close to the main operator but his legs are not protected. There are also cases where the operator needs to change his position during the procedure, for medical reasons, and stands close to the table without having his legs protected. The proper use of table shield can reduce the leg doses from 2 to 5 times.
- The tube should be placed below the operating table. There is a significant reduction at the eye (2-27 times) and hand doses (2-50 times). However, there is an increase at the leg doses which can be compensated by the use of properly positioned table shield.
- If the biplane configuration is used the proper use of lateral shield is very important because otherwise the eyes and hands are practically unshielded.
- The femoral access should be preferred, if it is possible, from the medical point of view, than the radial one. The doses, if the shields are properly used, are lower in the femoral access, by 2 to 7 times. However, it was noticed that the correct positioning of the ceiling shields are more of a challenge for femoral access.
- Going outside the operating room during the image acquisition is a practice which can reduce the doses significantly (4 to 16 times), especially the hand ones.

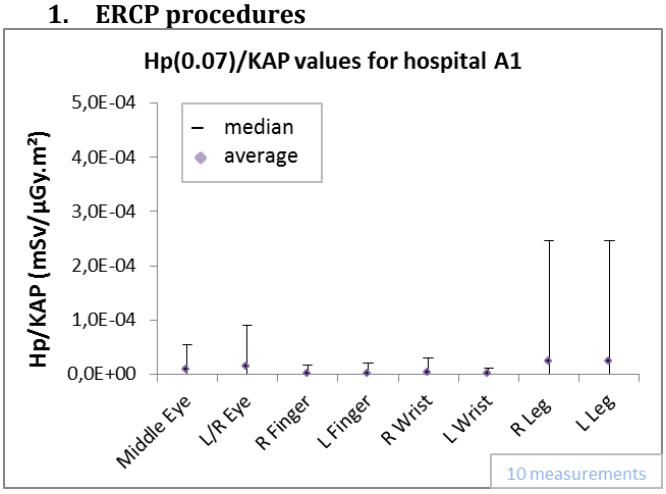
The maximum doses were found to be at the part of the operator which is close to the x ray tube. In the procedures that were examined the left wrist was found to be the position where the maximum dose was obtained most often, followed by the left finger (for embolizations, DSA PTA LL and pacemakers). Generally, the maximum doses were measured at the left wrist for the femoral access and at the left finger when the radial access is used or when the operator's hands are very close to the beam field. So both wrist and ring dosemeters are important for the routine monitoring.

7 References

1. WP1 first deliverable
2. WP1 second deliverable
3. International Commission on Radiation Units and Measurements. Conversion coefficients for use in radiological protection against external radiation. ICRU Report 57 (Bethesda, MD: ICRU) (1998).
4. WP1 simulations intermediate report

Appendix 1: Overview dose measurements per hospital

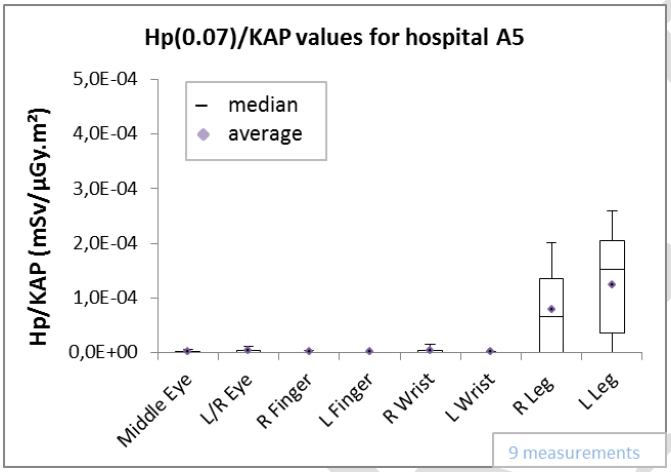
1. ERCP procedures



room protective equipment: table shield

tube configuration: below

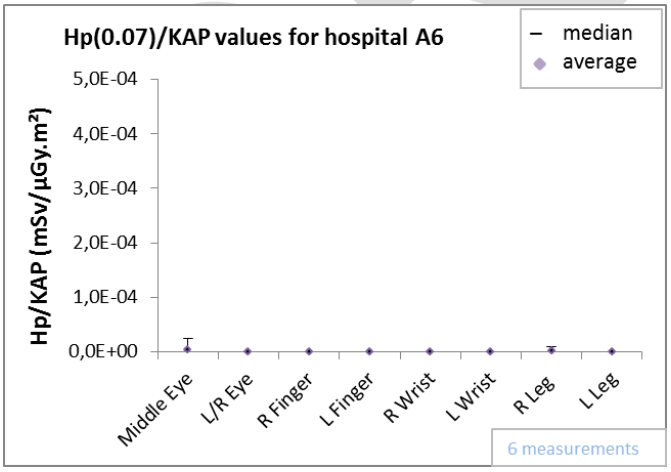
86% of measuremernts are 'zero' (LDL)



room protective equipment: 1 operator none (6 meas)
1 operator table shield (3 meas)

tube configuration: below

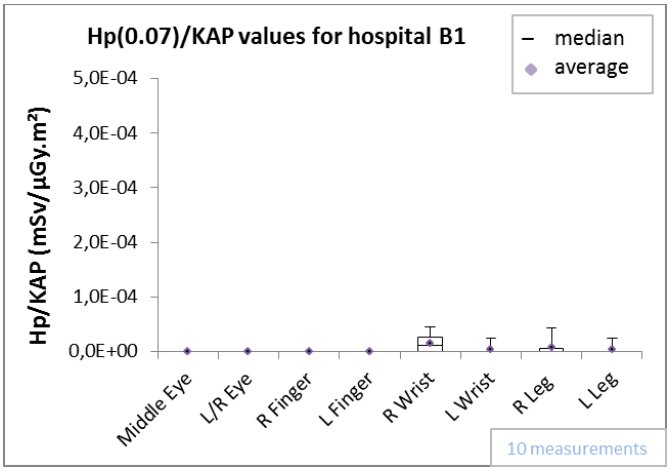
85% of measurements to finger, wrists and eyes are 'zero' (LDL)



room protective equipment: table shield

tube configuration: below

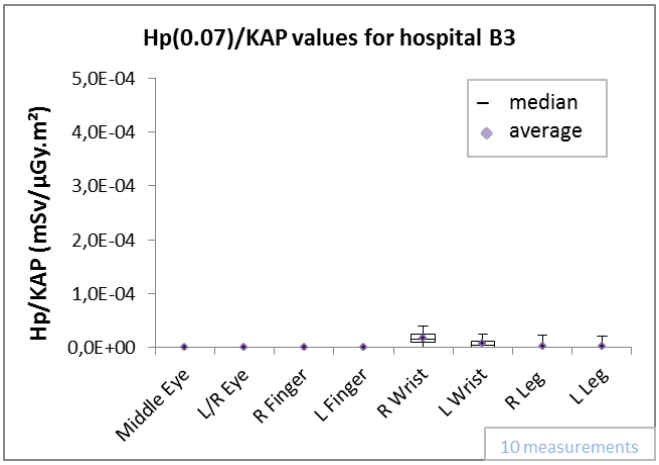
98% of measuremernts are 'zero' (LDL)



room protective equipment:
table + ceiling shield

tube configuration: above

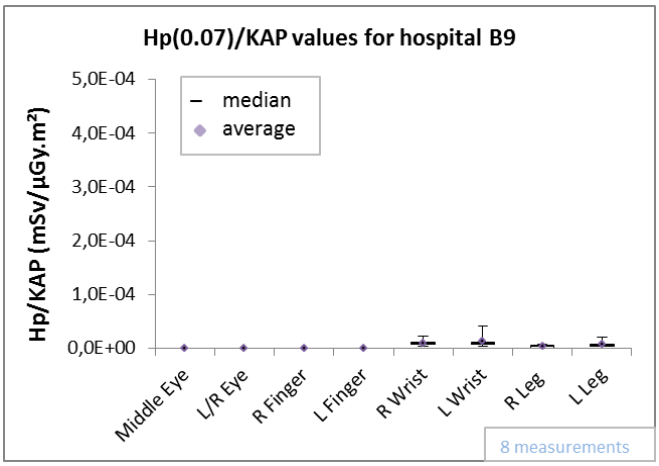
95% of measurements are 'zero' (LDL)



room protective equipment:
ceiling
table + ceiling (2/10 proc)

tube configuration: above

86% of measurements are 'zero' (LDL)



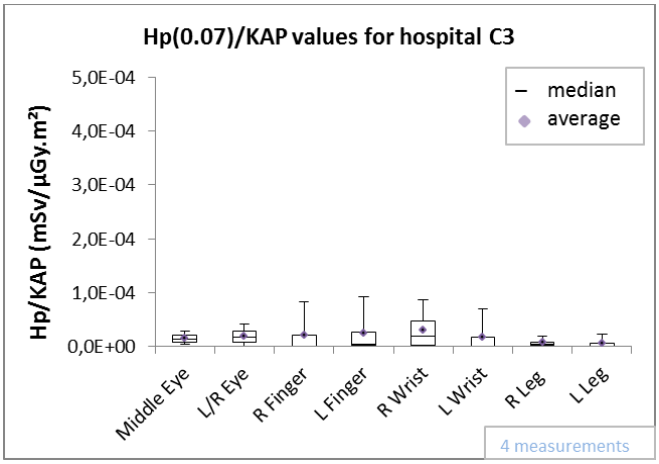
room protective equipment:
ceiling

tube configuration: above

73% of measurements are 'zero' (LDL)

Highest doses to the wrists

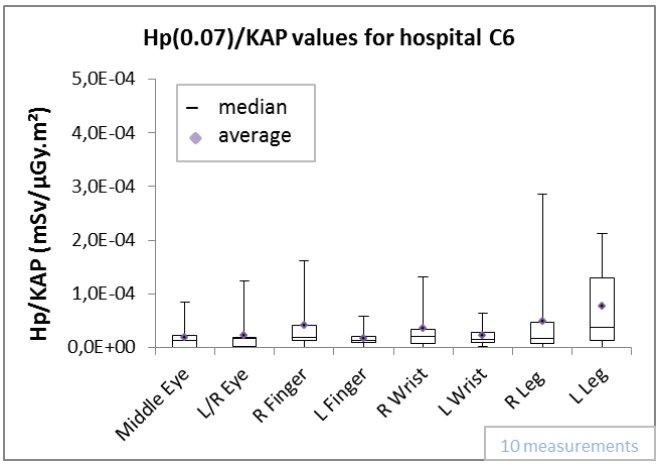
APPENDIX 1



room protective equipment: table + ceiling

tube configuration: below

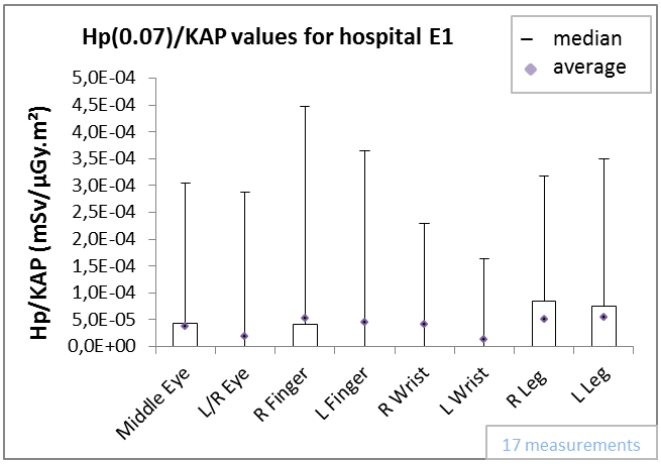
59% of measurements are 'zero' (LDL)



room protective equipment: table

tube configuration: below

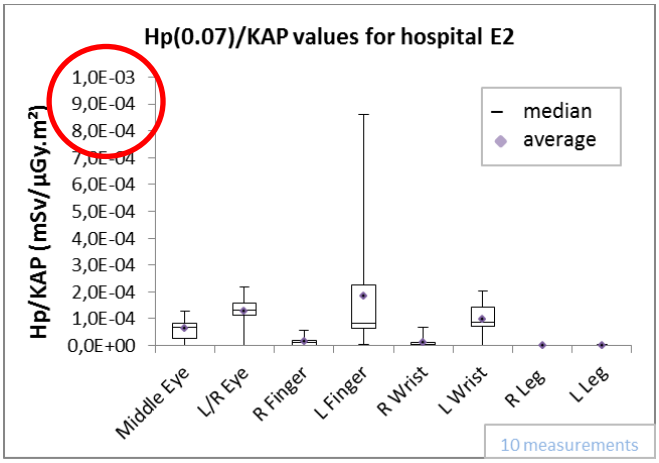
21% of measurements are 'zero' (LDL)



room protective equipment: ceiling shield
tabel + ceiling shield (4 proc)

tube configuration: below

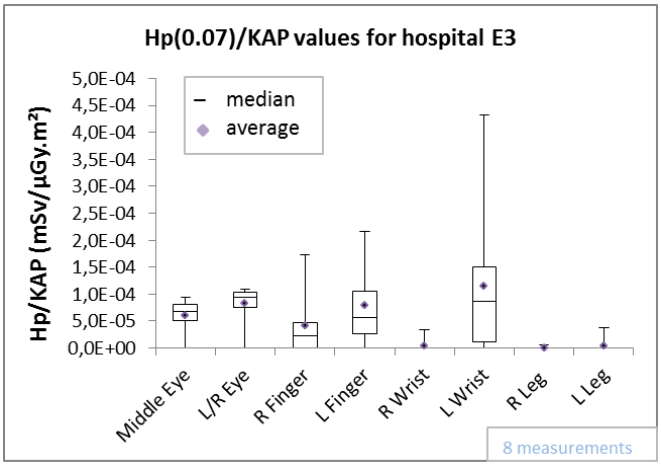
81% of measurements are 'zero' (LDL)



no room protective equipment

tube configuration: above

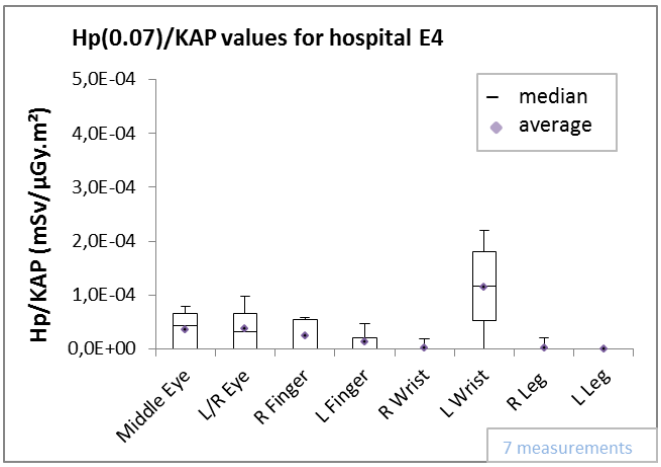
36% of measurements are 'zero' (LDL)



no room protective equipment

tube configuration: above

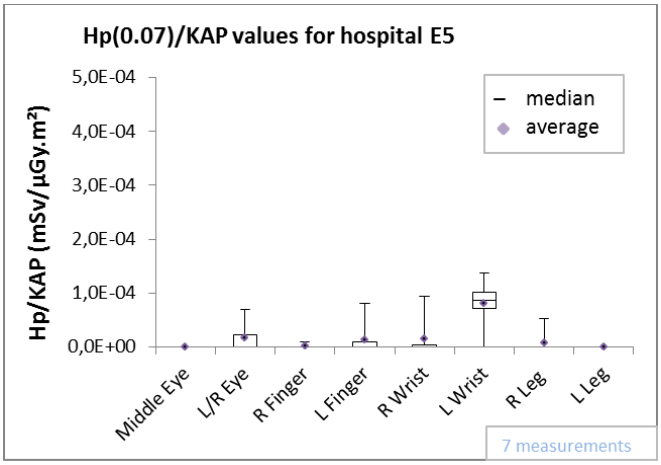
48% of measurements are 'zero' (LDL):
mainly legs and right sides



no room protective equipment

tube configuration: above

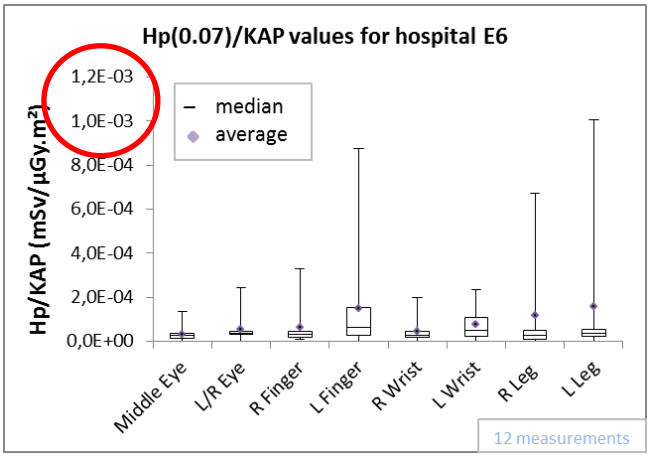
66% of measurements are 'zero' (LDL)



no room protective equipment

tube configuration: above

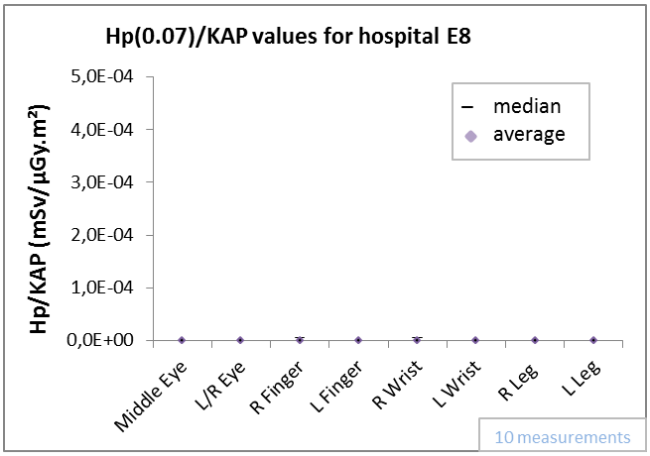
82% of measurements are 'zero' (LDL)



no room protective equipment

tube configuration: below

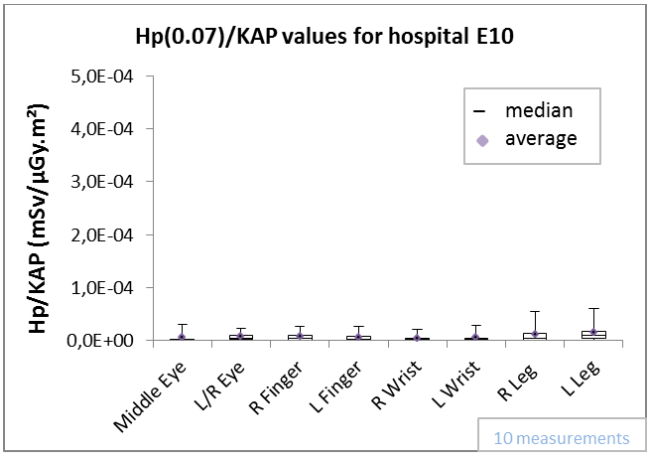
12% of measurements are 'zero' (LDL):



room protective equipment:
table + ceiling + patient shield

tube configuration: below

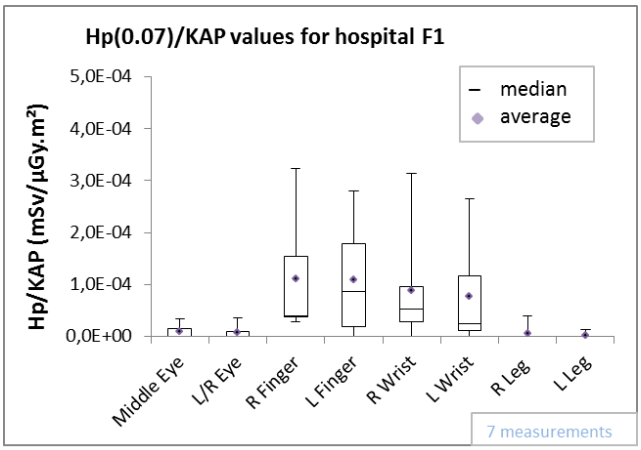
97% of measurements are 'zero' (LDL)



room protective equipment:
table shield

tube configuration: below

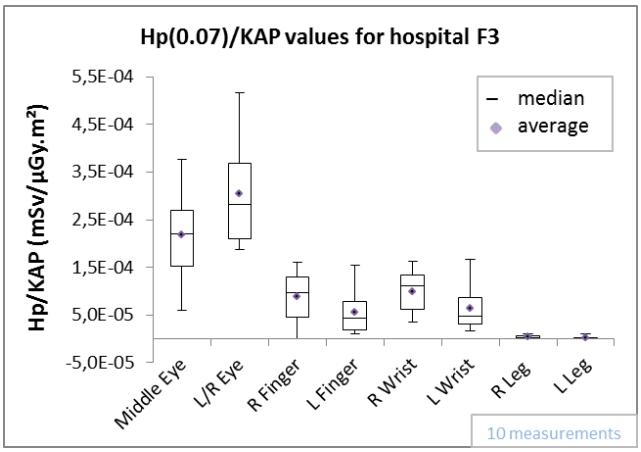
35% of measurements are 'zero' (LDL)



room protective equipment:
table shield

tube configuration: above

46% of measurements are 'zero' (LDL)
mainly legs and eyes

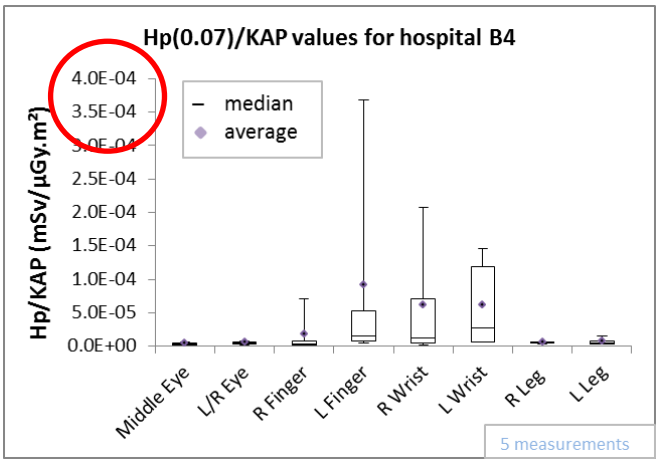


room protective equipment:
table shield

tube configuration: above

15% of measurements are 'zero' (LDL)
mainly legs

2. DSA PTA Re procedures

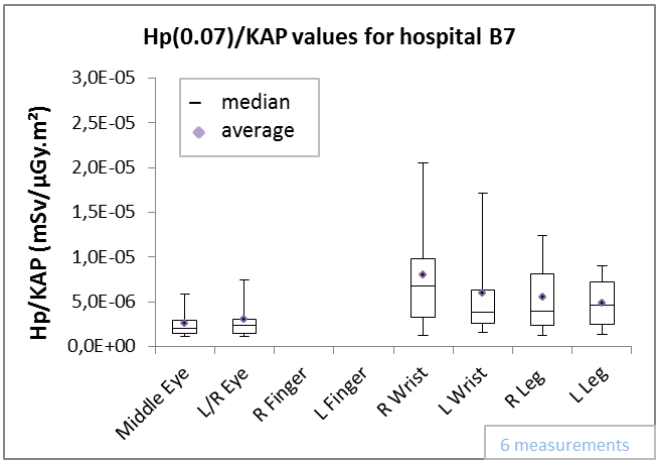


room protective equipment:
2 proc table shield
1 proc ceiling shield
2 proc table + ceiling shields

tube configuration: below

femoral access

1 proc: sometimes out during image acquisition

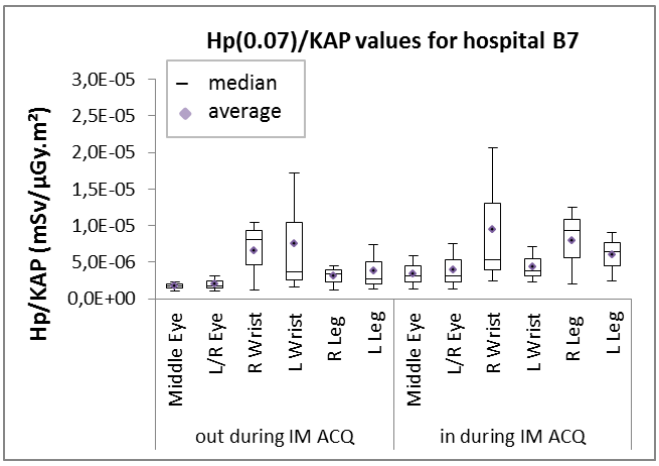


room protective equipment:
1 proc none
1 proc table shield
4 proc table + ceiling shields

tube configuration: below

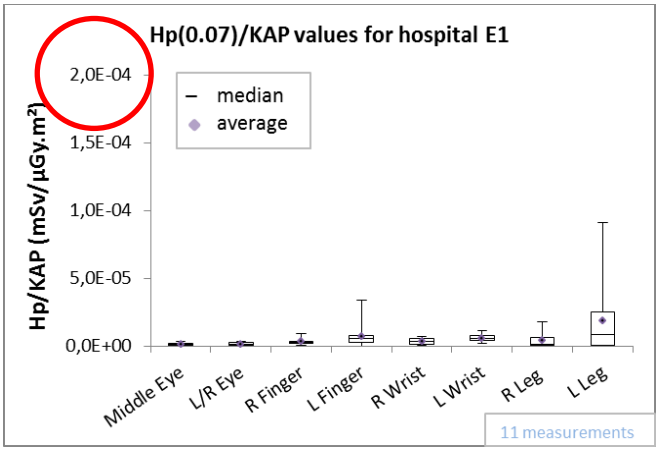
access: 3 femoral (pos 4)
3 radial (pos 3-7)

out during image acquisition:
3 proc: yes
3 proc: no



Influence of 'going out during image acquisition' on
- eyes
- legs

APPENDIX 1

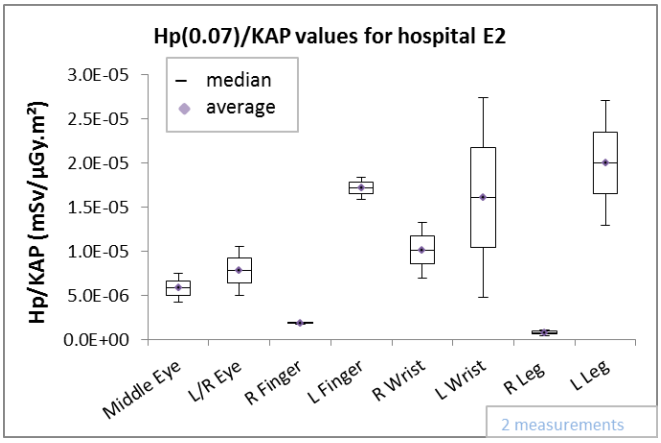


room protective equipment:
table + ceiling shields

tube configuration: below

femoral access

out during image acquisition:
9/11 proc: yes
2/11 proc: no

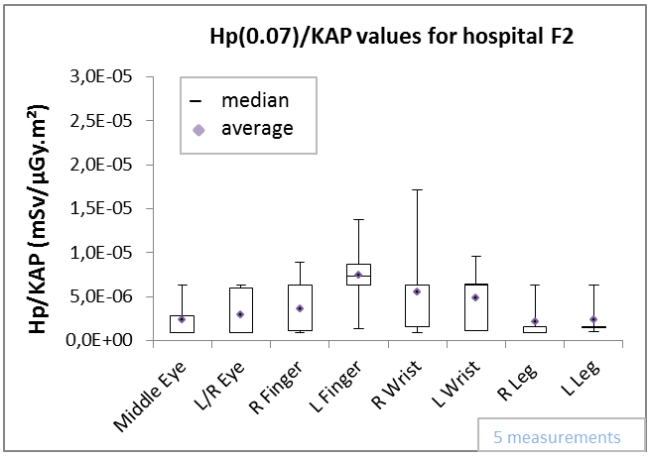


room protective equipment:
1 proc none
1 proc table shields

tube configuration: below

femoral access

out during image acquisition: no

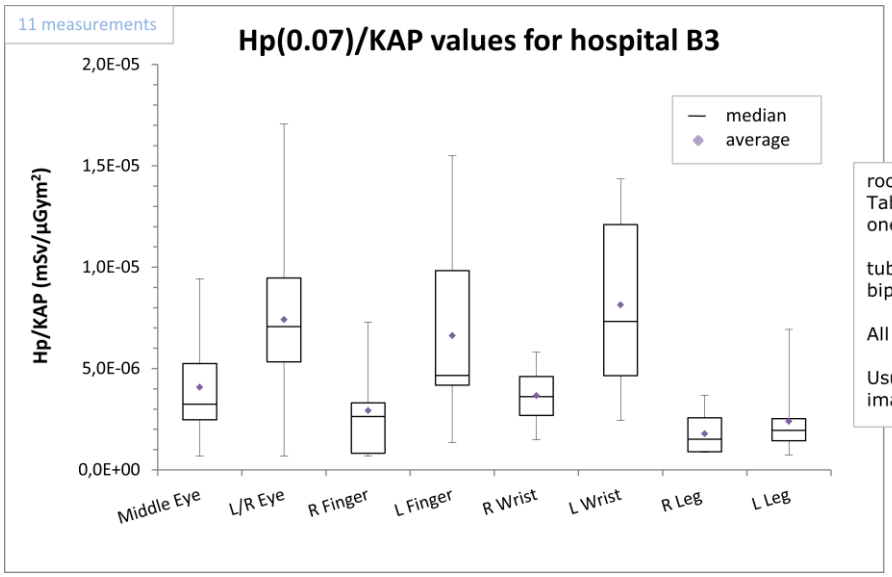


room protective equipment:
table + ceiling shields

tube configuration: below

out during image acquisition:
2/5 proc: yes
3/5 proc: no

3. DSA PTA Ca Ce

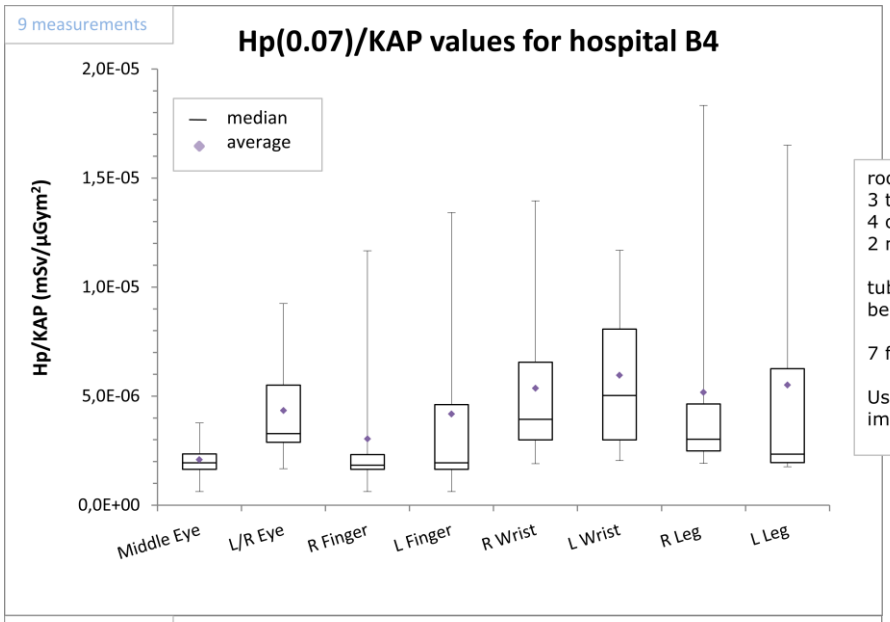


room protective equipment:
Table+ceiling (covering only one tube)

tube configuration:
biplane

All femoral access

Usually IN the room during image acquisitions

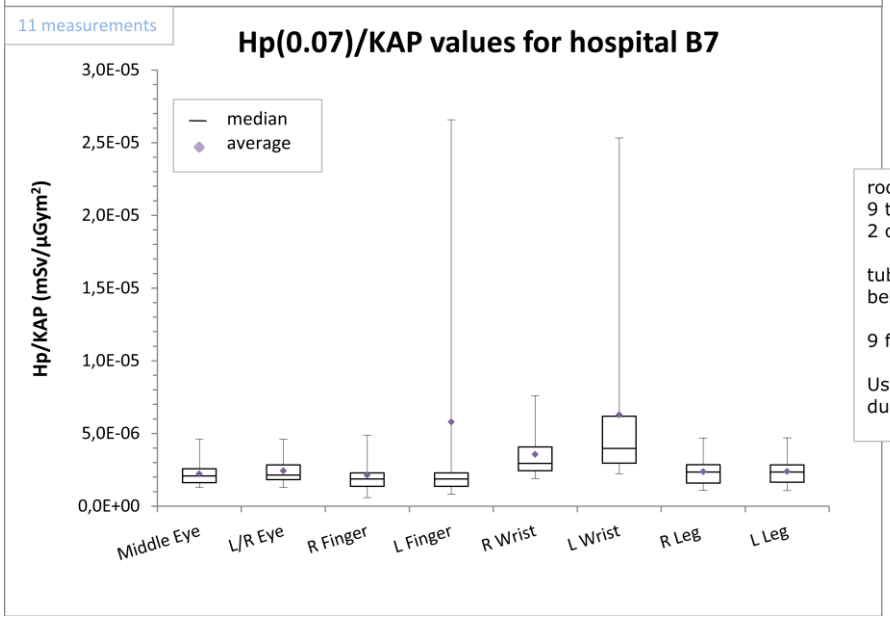


room protective equipment:
3 table+ceiling
4 only table
2 none

tube configuration:
below

7 femoral, 2 radial access

Usually IN the room during image acquisitions



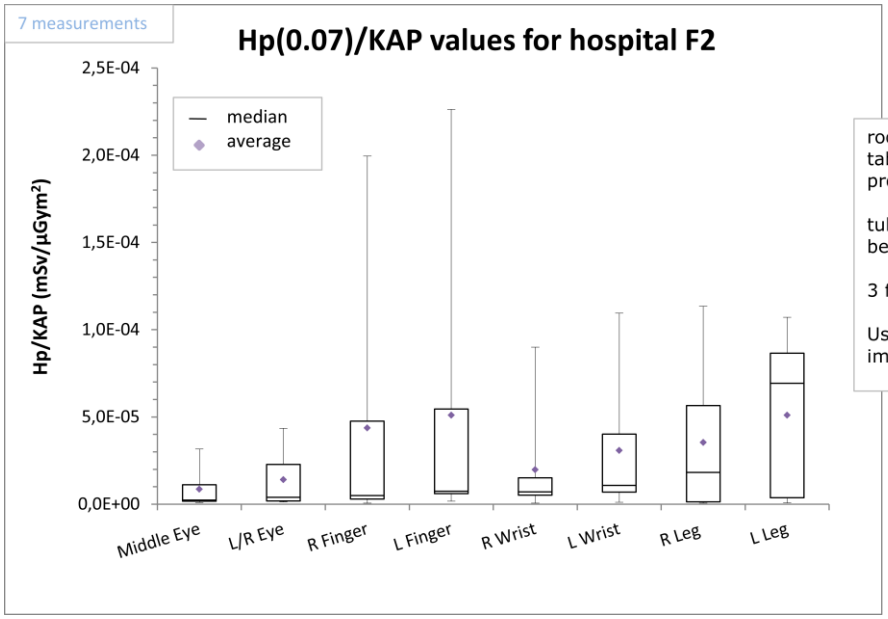
room protective equipment:
9 table+ceiling
2 only table

tube configuration:
below

9 femoral, 2 radial access

Usually OUT of the room during image acquisitions

APPENDIX 1

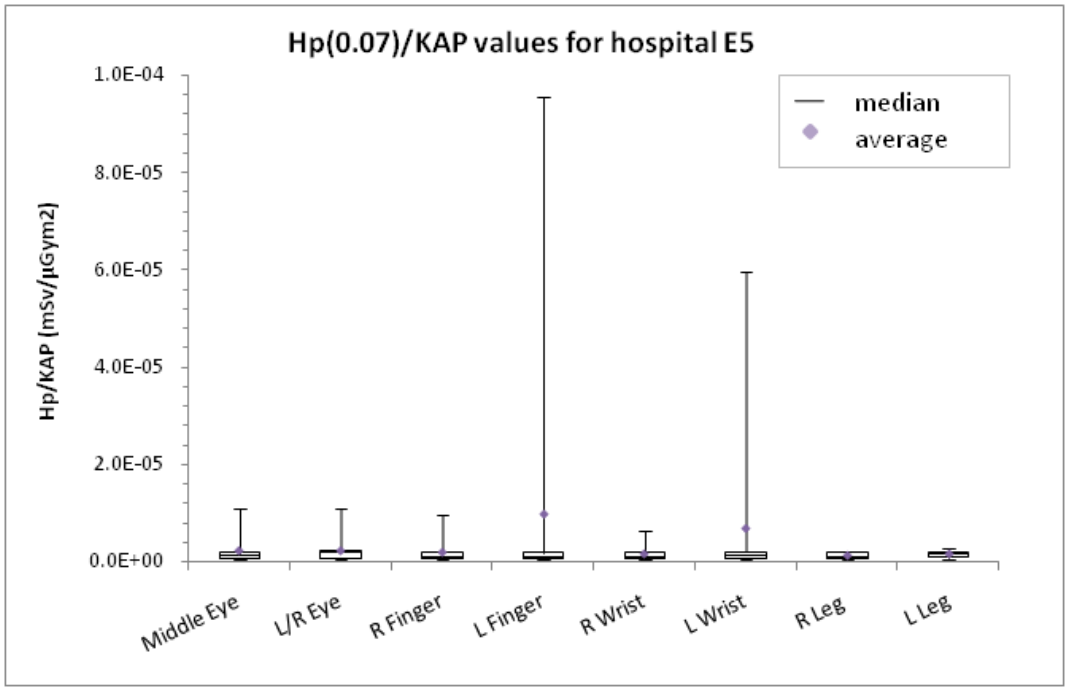


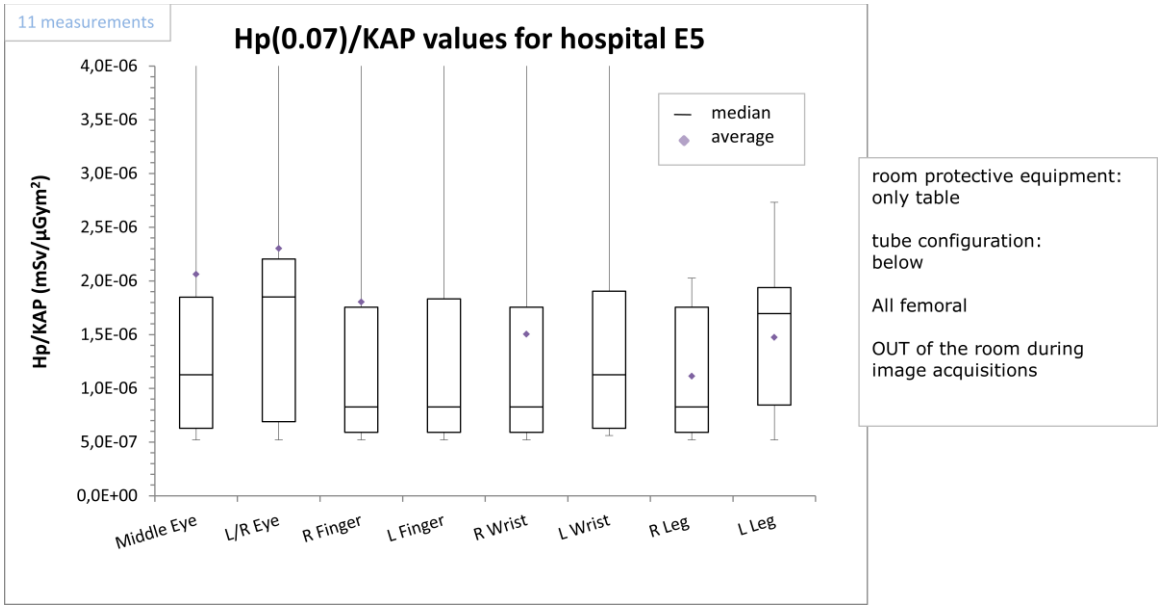
room protective equipment: table+ceiling (often not properly used)

tube configuration: below

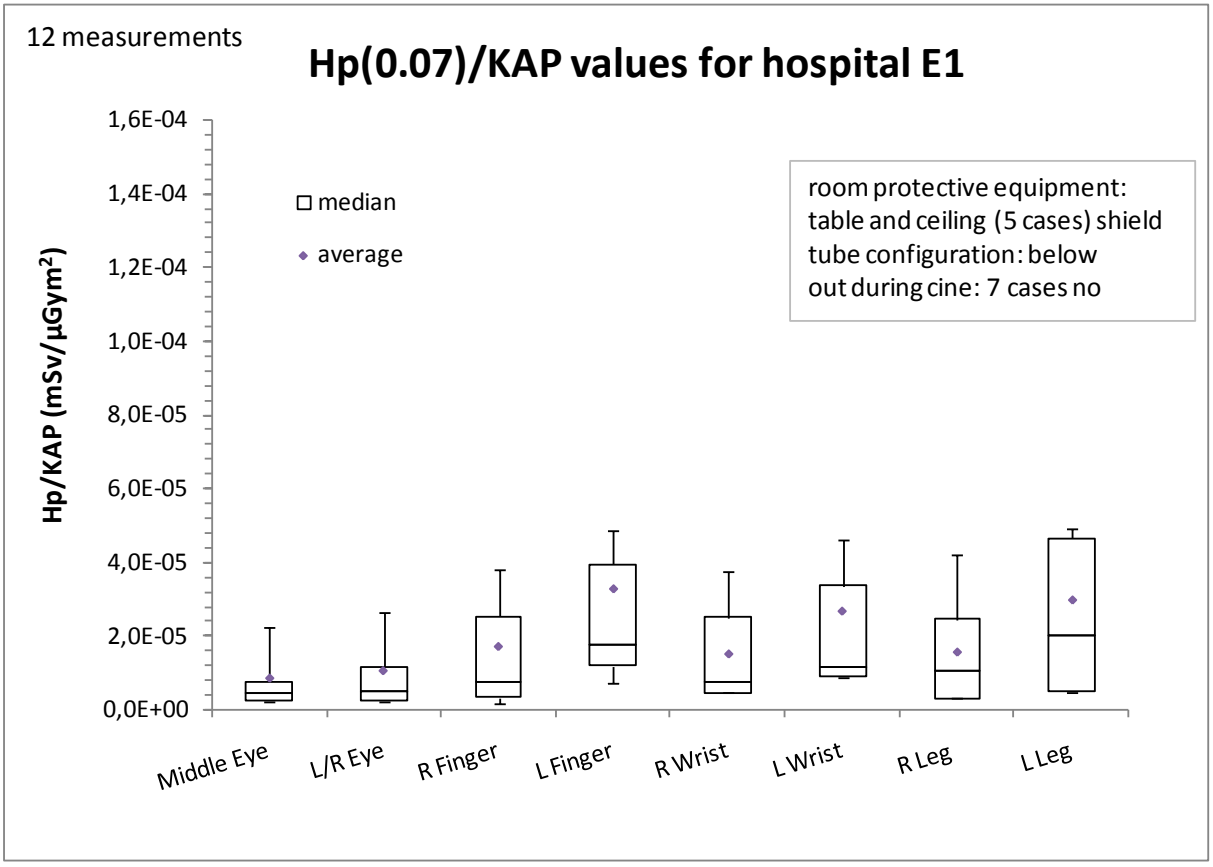
3 femoral, 4 radial access

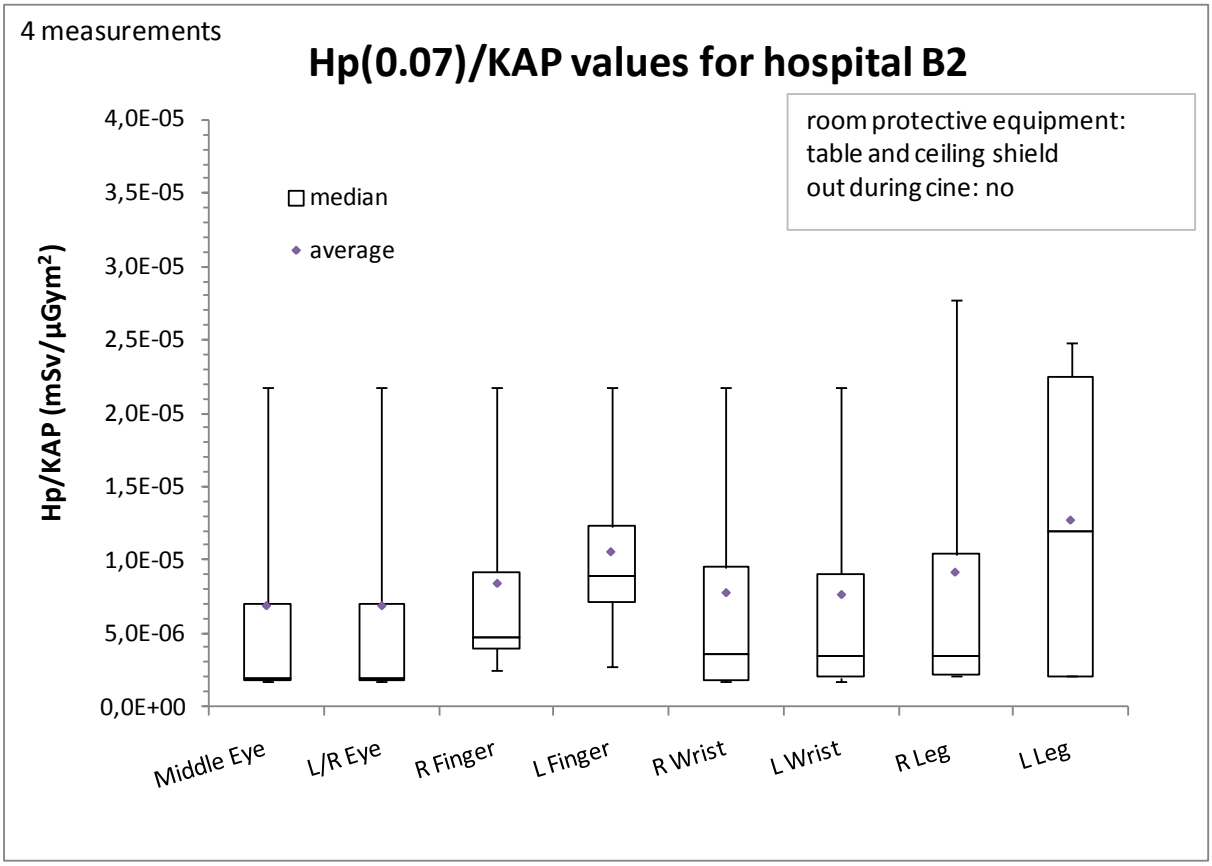
Usually IN the room during image acquisitions

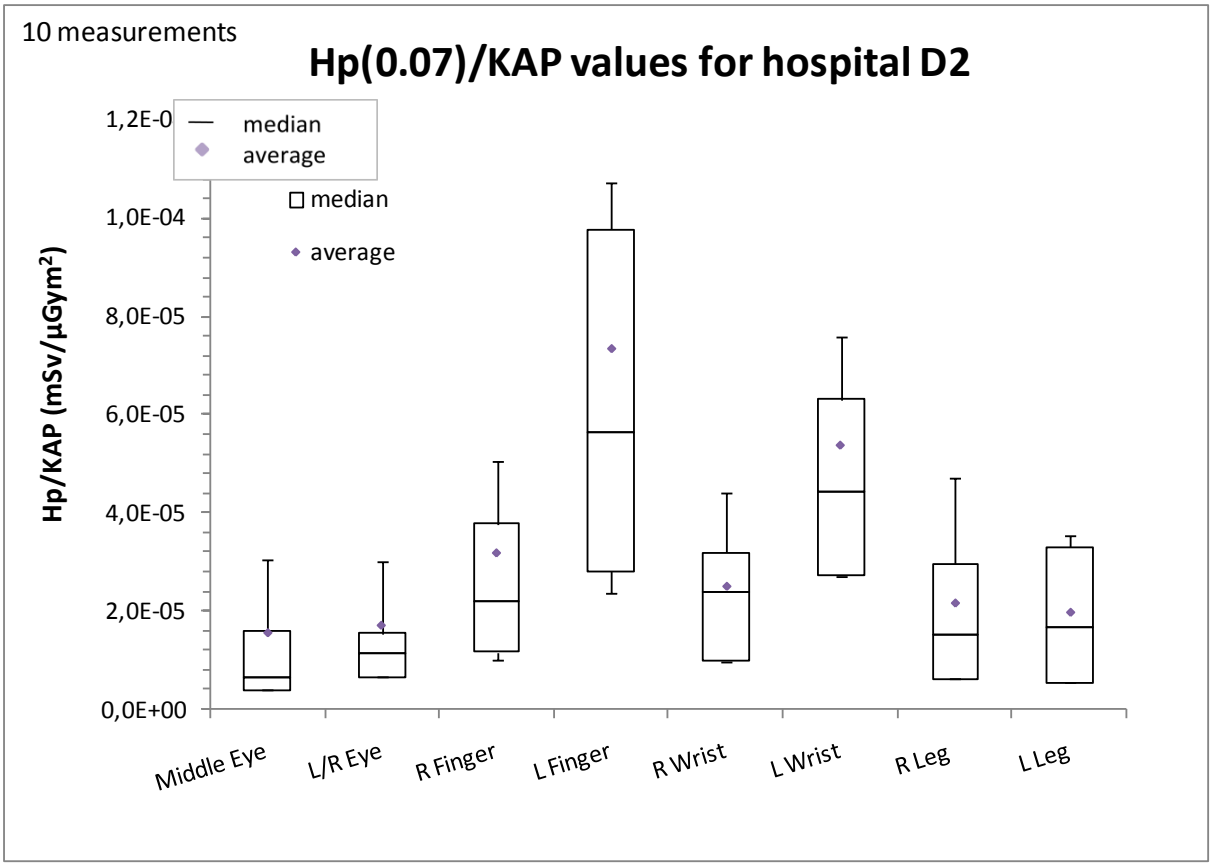


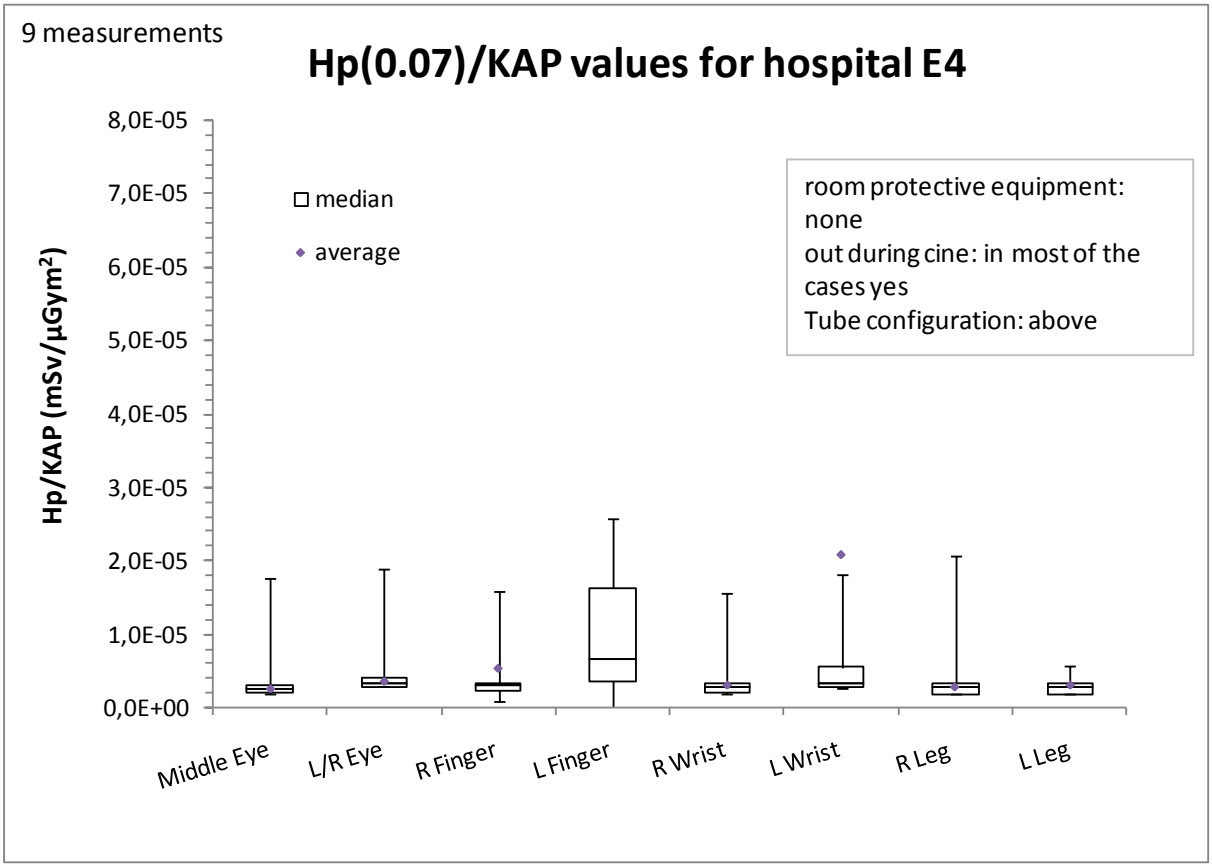

11 measurements
Hp(0.07)/KAP values for hospital E5
Hp/KAP (mSv/µGym²)
4,0E-06
3,5E-06
3,0E-06
2,5E-06
2,0E-06
1,5E-06
1,0E-06
5,0E-07
0,0E+00
median
average
Middle Eye
L/R Eye
R Finger
L Finger
R Wrist
L Wrist
R Leg
L Leg
room protective equipment:
only table
tube configuration:
below
All femoral
OUT of the room during
image acquisitions

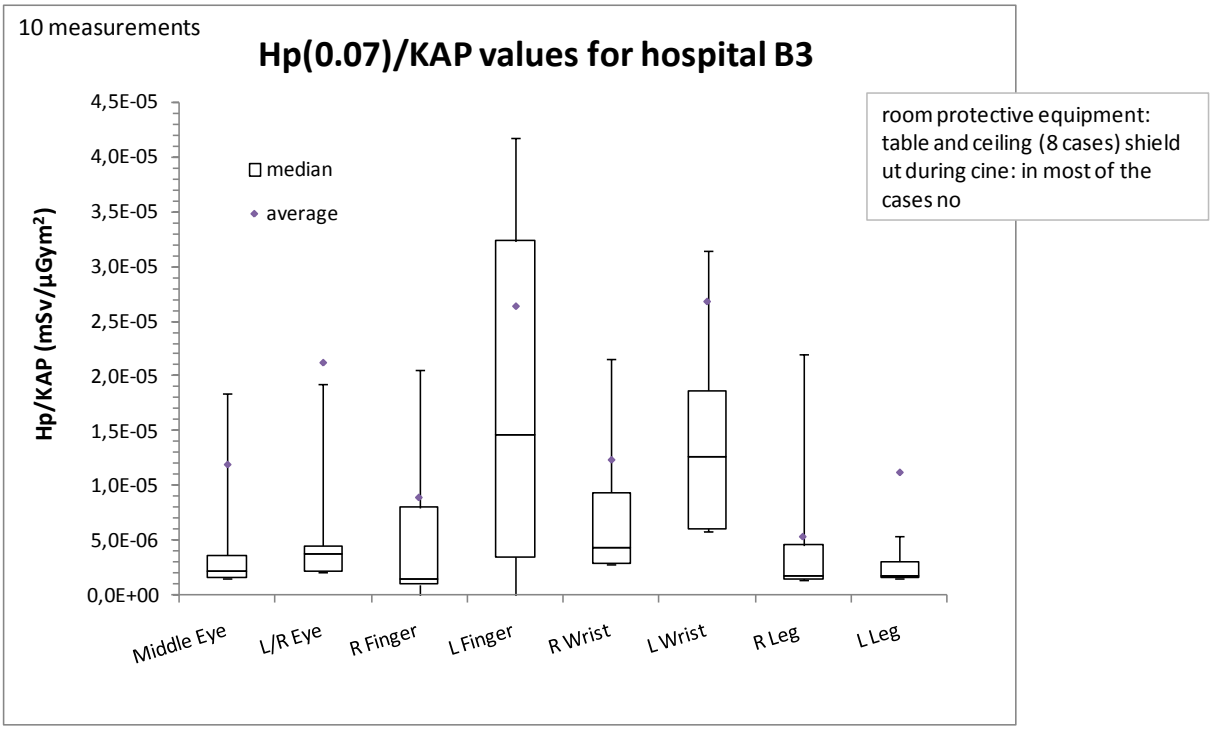
4. DSA PTS LL


12 measurements
Hp(0.07)/KAP values for hospital E1
Hp/KAP (mSv/µGym²)
1,6E-04
1,4E-04
1,2E-04
1,0E-04
8,0E-05
6,0E-05
4,0E-05
2,0E-05
0,0E+00
median
average
Middle Eye
L/R Eye
R Finger
L Finger
R Wrist
L Wrist
R Leg
L Leg
room protective equipment:
table and ceiling (5 cases) shield
tube configuration: below
out during cine: 7 cases no

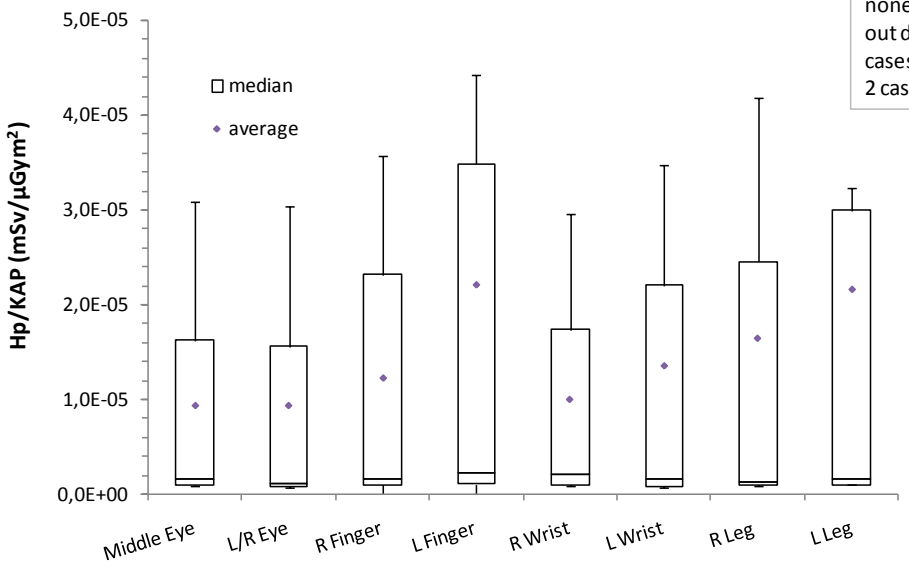

4 measurements
Hp(0.07)/KAP values for hospital B2
room protective equipment:
table and ceiling shield
out during cine: no
median
average
Hp/KAP (mSv/µGym²)
4,0E-05
3,5E-05
3,0E-05
2,5E-05
2,0E-05
1,5E-05
1,0E-05
5,0E-06
0,0E+00
Middle Eye
L/R Eye
R Finger
L Finger
R Wrist
L Wrist
R Leg
L Leg


10 measurements
Hp(0.07)/KAP values for hospital D2
median
average
median
average
Hp/KAP (mSv/µGym²)
1,2E-0
1,0E-04
8,0E-05
6,0E-05
4,0E-05
2,0E-05
0,0E+00
Middle Eye
L/R Eye
R Finger
L Finger
R Wrist
L Wrist
R Leg
L Leg


9 measurements
Hp(0.07)/KAP values for hospital E4
Hp/KAP (mSv/µGym²)
8,0E-05
7,0E-05
6,0E-05
5,0E-05
4,0E-05
3,0E-05
2,0E-05
1,0E-05
0,0E+00
median
average
room protective equipment: none
out during cine: in most of the cases yes
Tube configuration: above
Middle Eye
L/R Eye
R Finger
L Finger
R Wrist
L Wrist
R Leg
L Leg

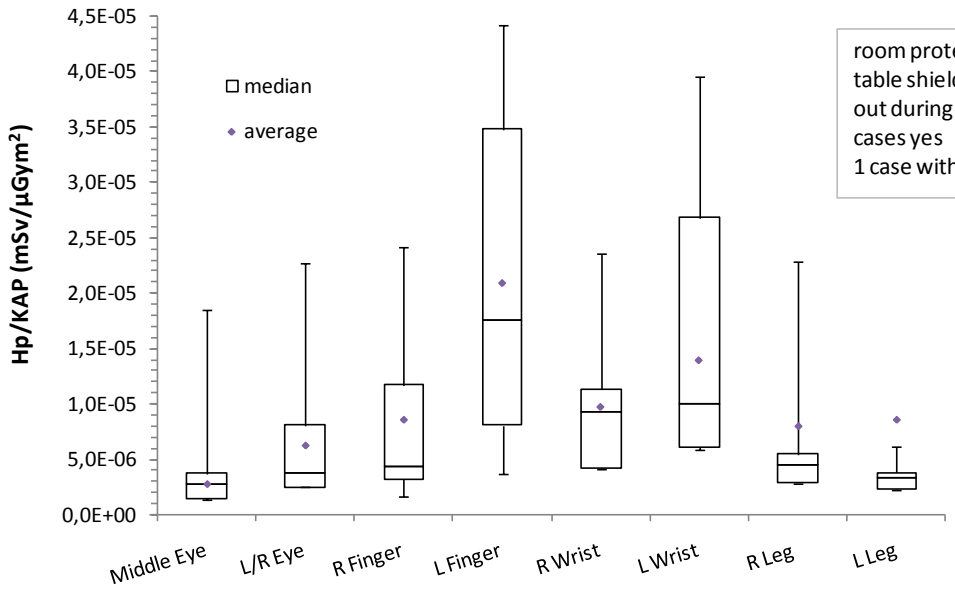

10 measurements
Hp(0.07)/KAP values for hospital B3
Hp/KAP (mSv/µGym²)
4,5E-05
4,0E-05
3,5E-05
3,0E-05
2,5E-05
2,0E-05
1,5E-05
1,0E-05
5,0E-06
0,0E+00
median
average
room protective equipment: table and ceiling (8 cases) shield
ut during cine: in most of the cases no
Middle Eye
L/R Eye
R Finger
L Finger
R Wrist
L Wrist
R Leg
L Leg

16 measurements

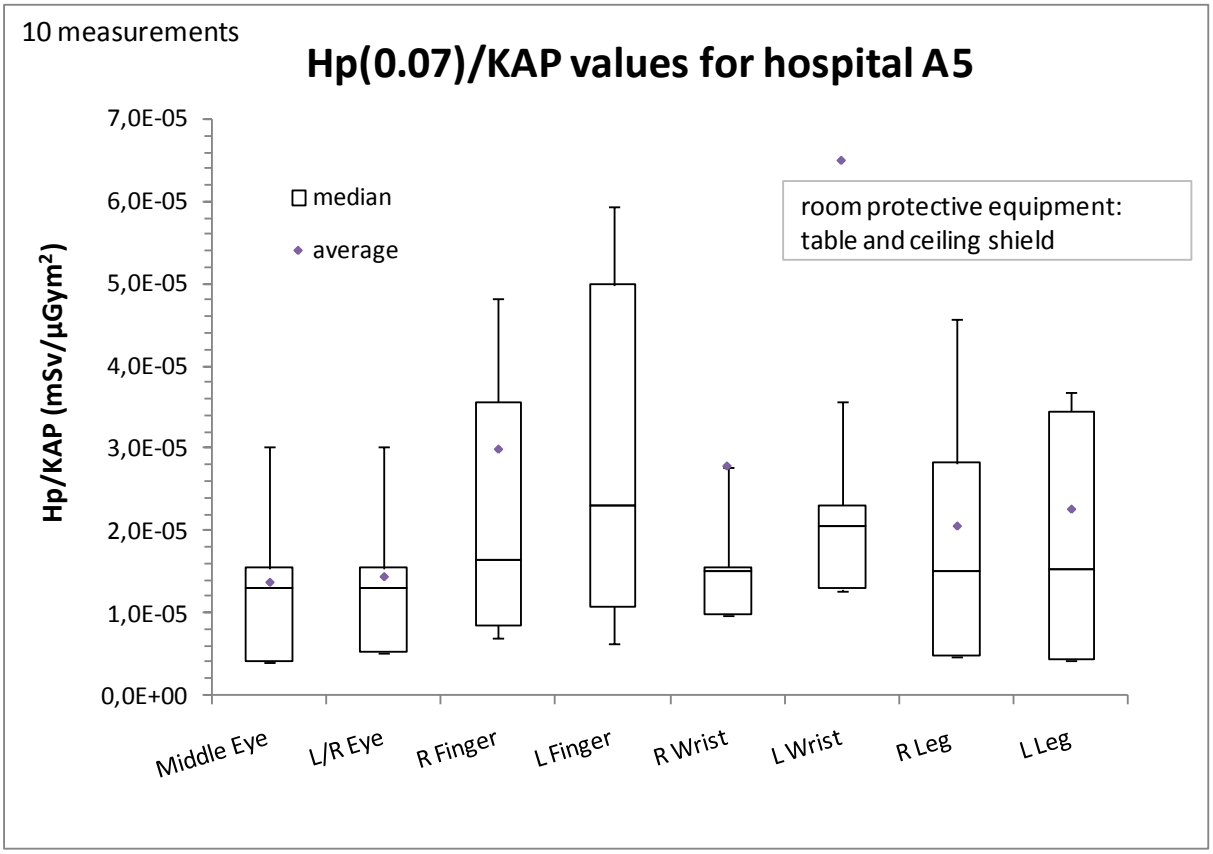


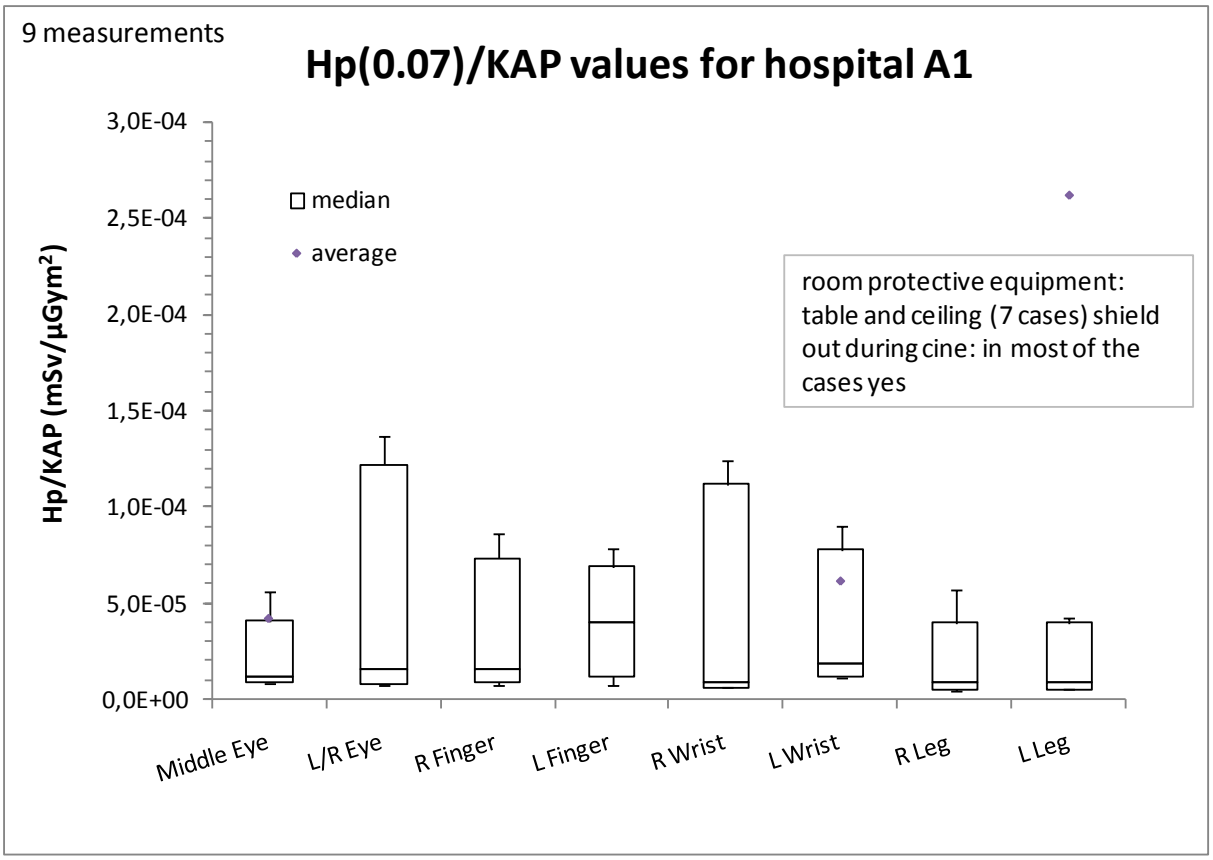
room protective equipment:
none or table shileld in 10 cases
out during cine: in most of the cases yes (10 cases)
2 cases with radial access

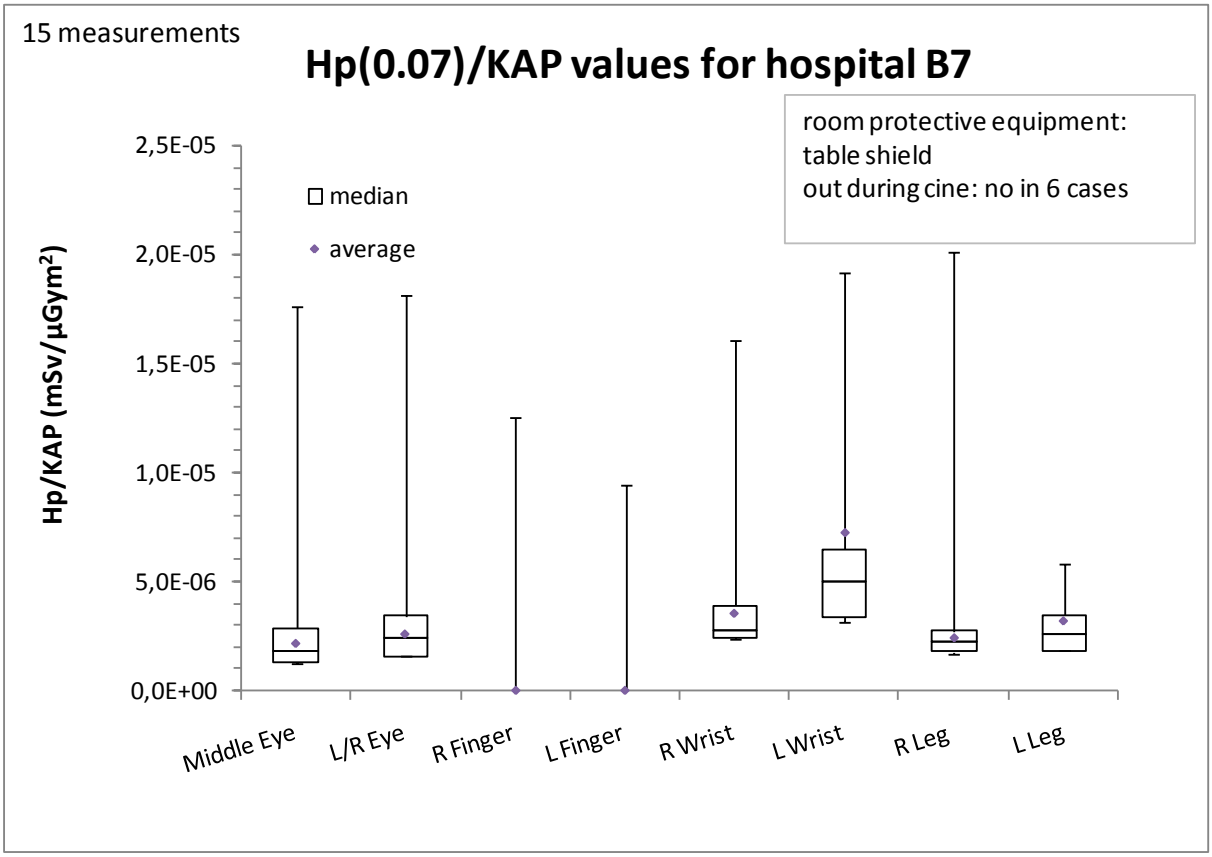
13 measurements

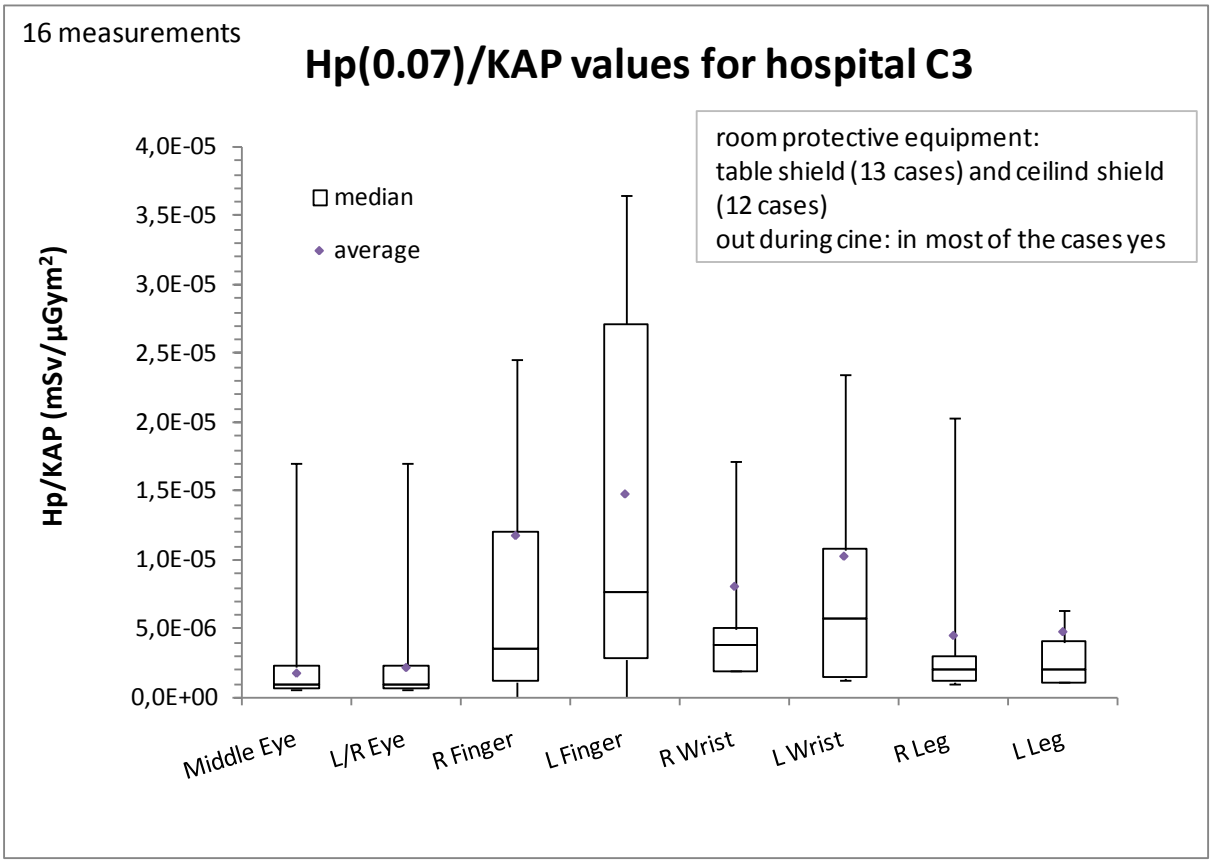


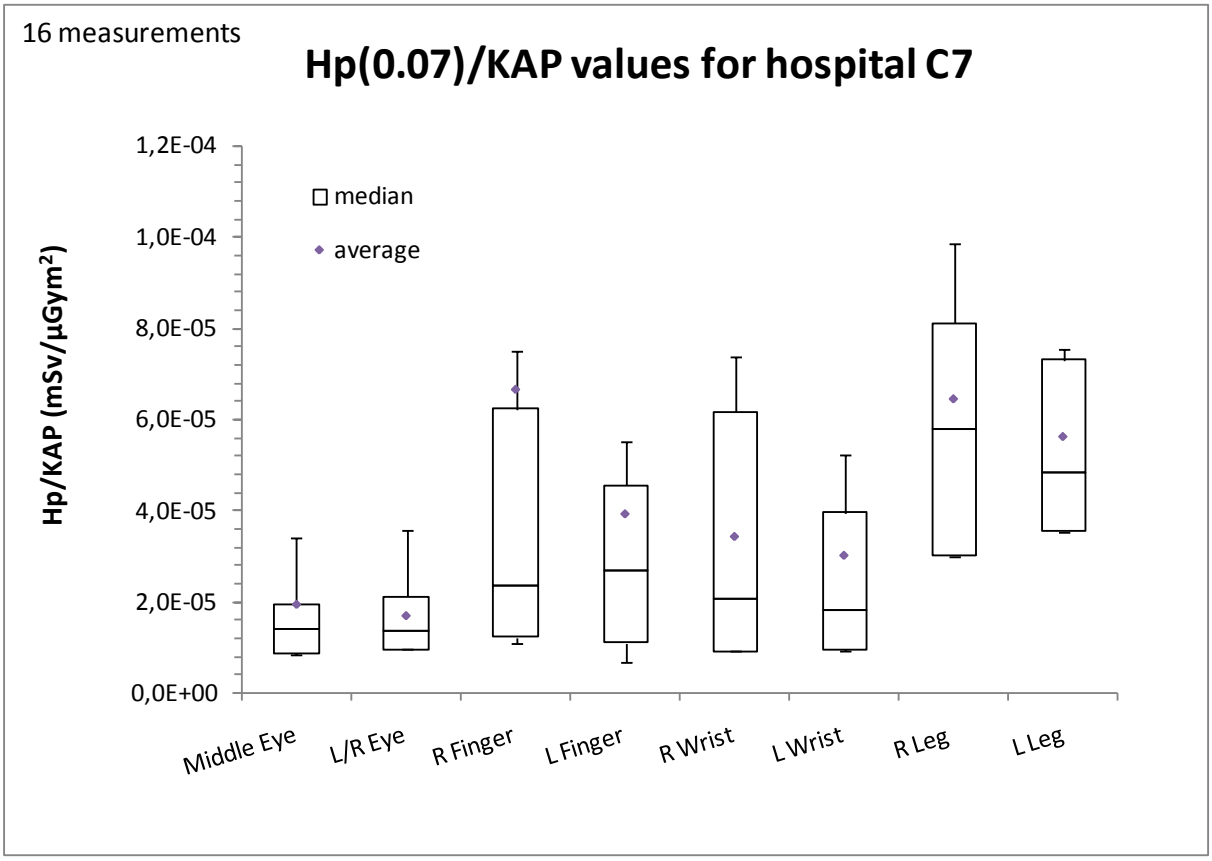
room protective equipment:
table shield
out during cine: in most of the cases yes
1 case with radial access

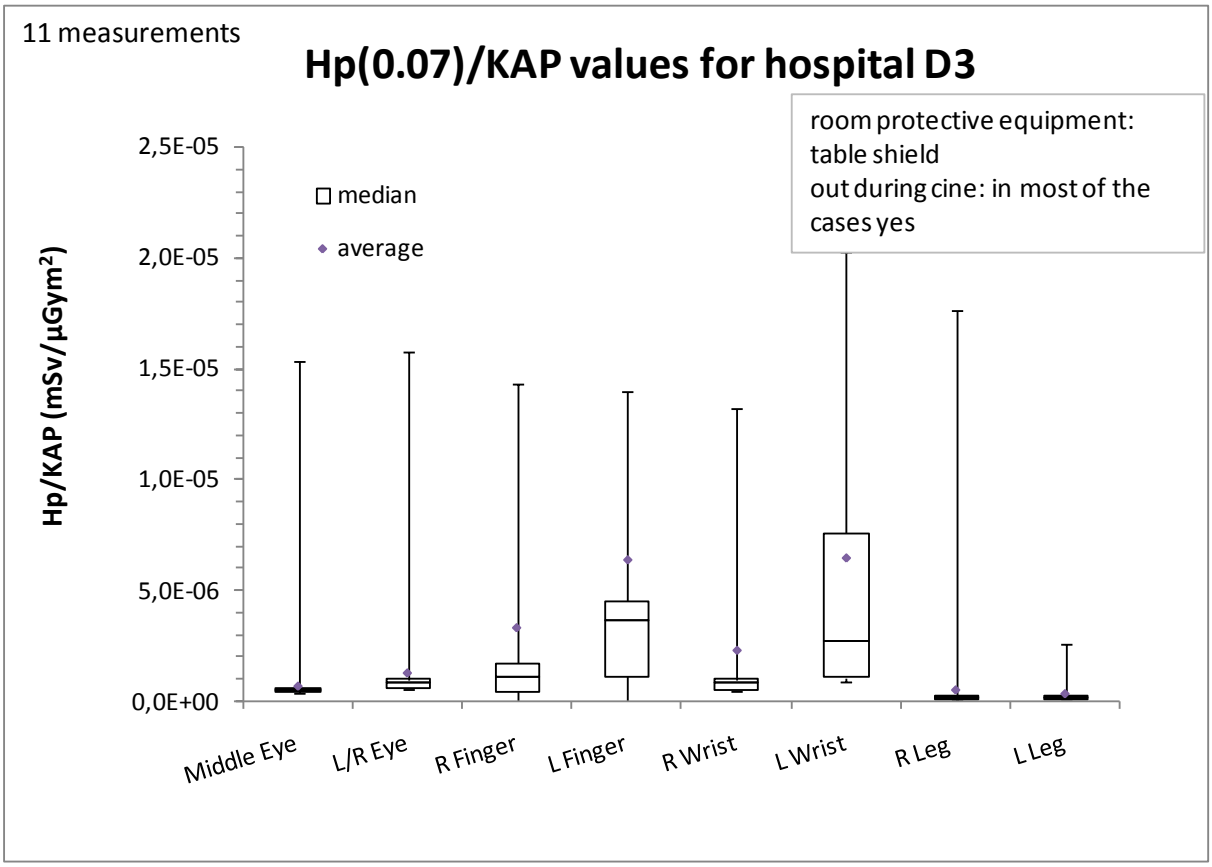

10 measurements
Hp(0.07)/KAP values for hospital A5
Hp/KAP (mSv/µGym²)
7,0E-05
6,0E-05
5,0E-05
4,0E-05
3,0E-05
2,0E-05
1,0E-05
0,0E+00
median
average
room protective equipment: table and ceiling shield
Middle Eye
L/R Eye
R Finger
L Finger
R Wrist
L Wrist
R Leg
L Leg

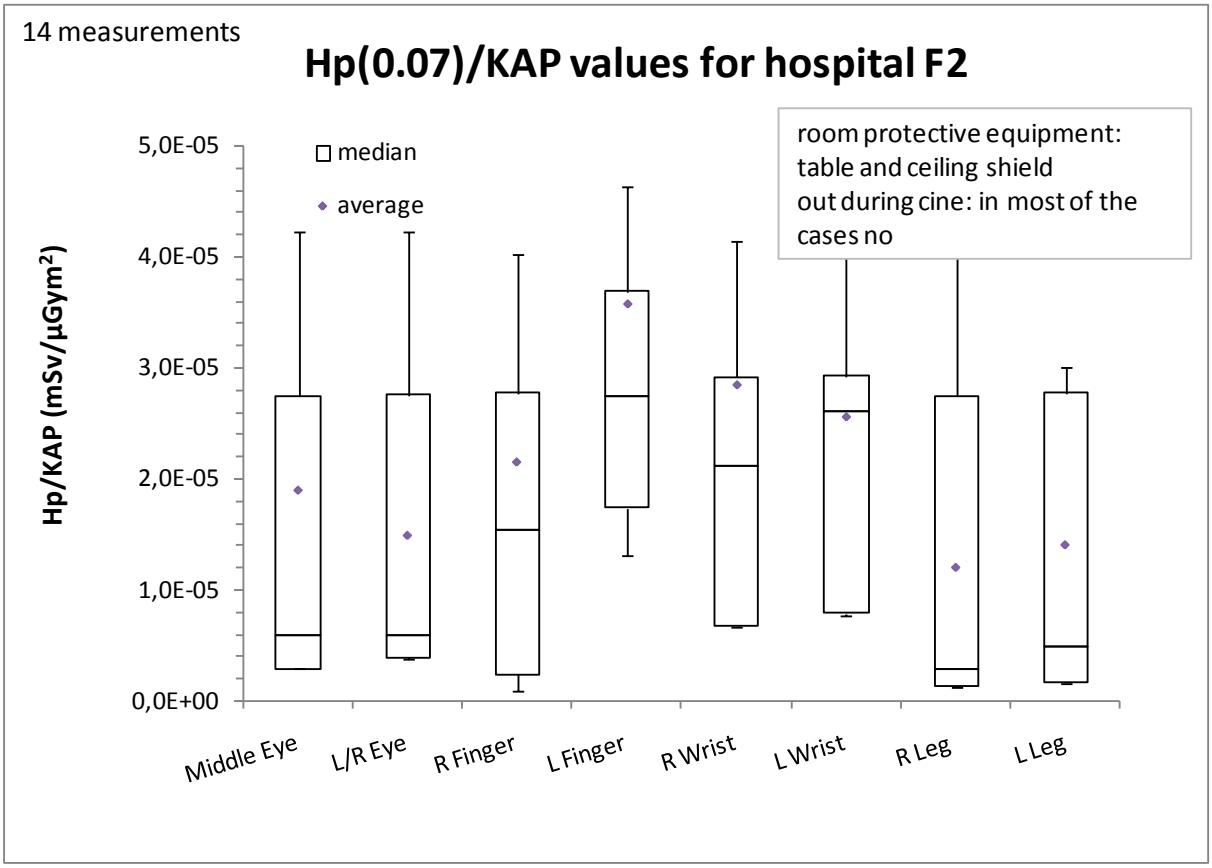

9 measurements
Hp(0.07)/KAP values for hospital A1
Hp/KAP (mSv/µGym²)
3,0E-04
2,5E-04
2,0E-04
1,5E-04
1,0E-04
5,0E-05
0,0E+00
median
average
room protective equipment: table and ceiling (7 cases) shield out during cine: in most of the cases yes
Middle Eye
L/R Eye
R Finger
L Finger
R Wrist
L Wrist
R Leg
L Leg

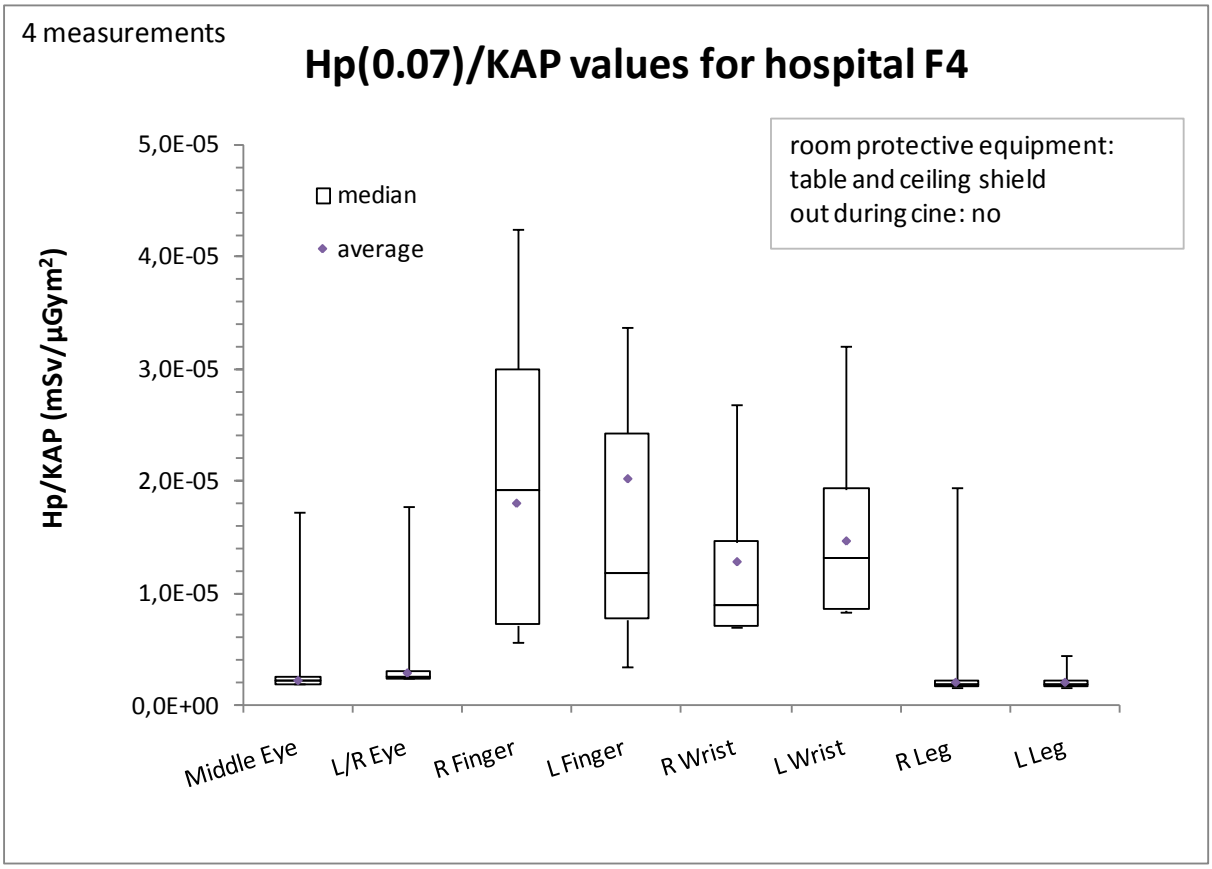

15 measurements
Hp(0.07)/KAP values for hospital B7
room protective equipment:
table shield
out during cine: no in 6 cases
median
average
Hp/KAP (mSv/µGym²)
2,5E-05
2,0E-05
1,5E-05
1,0E-05
5,0E-06
0,0E+00
Middle Eye
L/R Eye
R Finger
L Finger
R Wrist
L Wrist
R Leg
L Leg


16 measurements
Hp(0.07)/KAP values for hospital C3
room protective equipment:
table shield (13 cases) and ceilind shield (12 cases)
out during cine: in most of the cases yes
median
average
Hp/KAP (mSv/µGym²)
4,0E-05
3,5E-05
3,0E-05
2,5E-05
2,0E-05
1,5E-05
1,0E-05
5,0E-06
0,0E+00
Middle Eye
L/R Eye
R Finger
L Finger
R Wrist
L Wrist
R Leg
L Leg

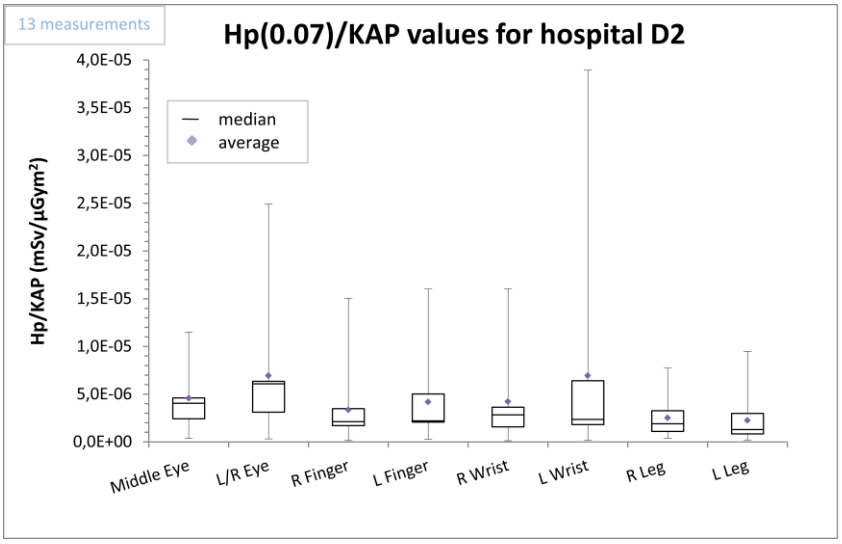

16 measurements
Hp(0.07)/KAP values for hospital C7
Hp/KAP (mSv/µGym²)
1,2E-04
1,0E-04
8,0E-05
6,0E-05
4,0E-05
2,0E-05
0,0E+00
median
average
Middle Eye
L/R Eye
R Finger
L Finger
R Wrist
L Wrist
R Leg
L Leg


11 measurements
Hp(0.07)/KAP values for hospital D3
room protective equipment:
table shield
out during cine: in most of the cases yes
Hp/KAP (mSv/µGym²)
2,5E-05
2,0E-05
1,5E-05
1,0E-05
5,0E-06
0,0E+00
median
average
Middle Eye
L/R Eye
R Finger
L Finger
R Wrist
L Wrist
R Leg
L Leg


14 measurements
Hp(0.07)/KAP values for hospital F2
room protective equipment:
table and ceiling shield
out during cine: in most of the cases no
median
average
Hp/KAP (mSv/µGym²)
5,0E-05
4,0E-05
3,0E-05
2,0E-05
1,0E-05
0,0E+00
Middle Eye
L/R Eye
R Finger
L Finger
R Wrist
L Wrist
R Leg
L Leg


4 measurements
Hp(0.07)/KAP values for hospital F4
room protective equipment:
table and ceiling shield
out during cine: no
median
average
Hp/KAP (mSv/µGym²)
5,0E-05
4,0E-05
3,0E-05
2,0E-05
1,0E-05
0,0E+00
Middle Eye
L/R Eye
R Finger
L Finger
R Wrist
L Wrist
R Leg
L Leg

5. Embolization procedures

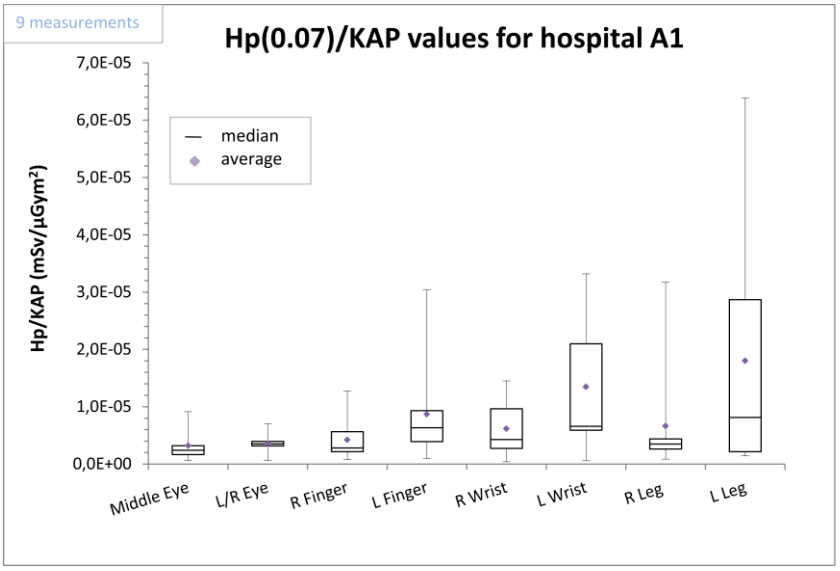


room protective equipment: only table

tube configuration: below

7 brain embolisations

6 out, 7 in the room during image acquisitions

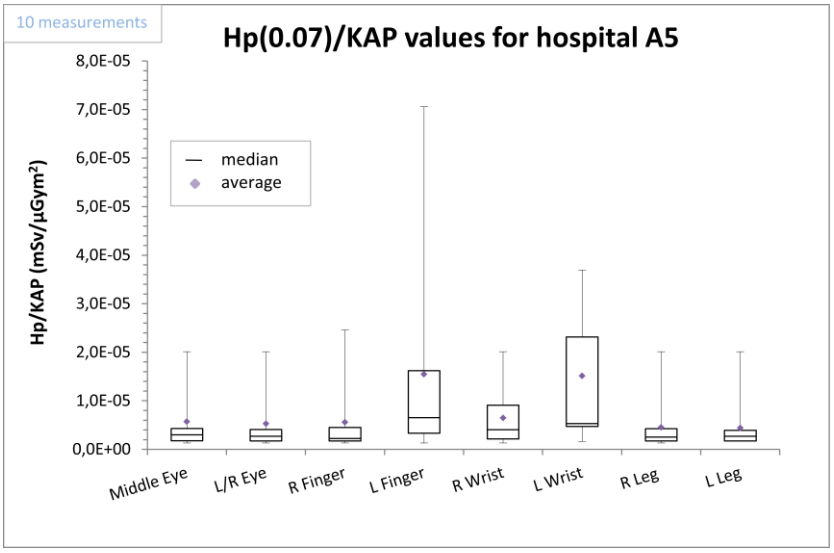


room protective equipment: table and ceiling

tube configuration: below

7 chemoembolisations

mostly out of the room during image acquisitions

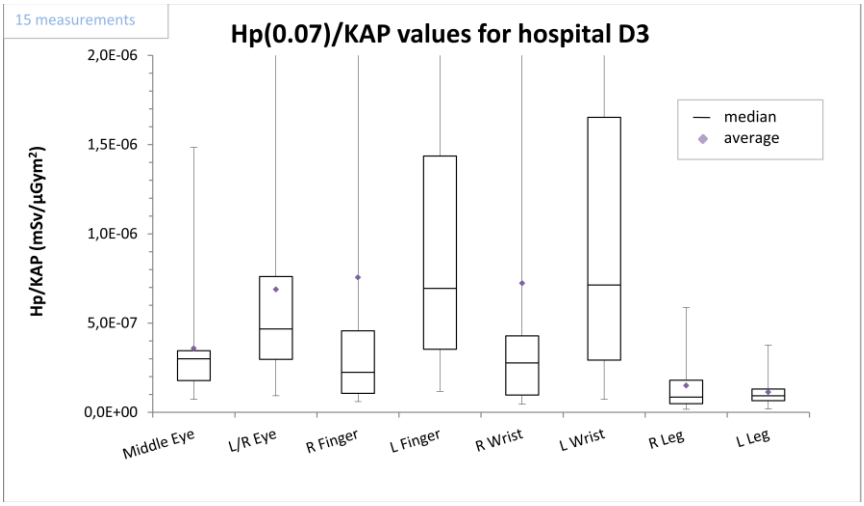


room protective equipment: table and ceiling

tube configuration: below

6 chemoembolisations

mostly in the room during image acquisitions

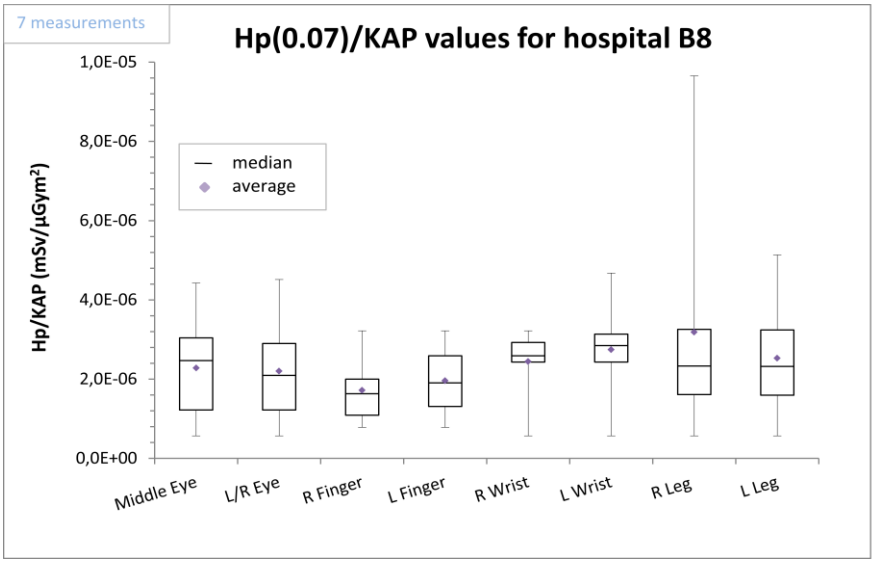


room protective equipment:
only table

tube configuration: below

various embolisation types
(mostly renal)

mostly out of the room during
image acquisitions

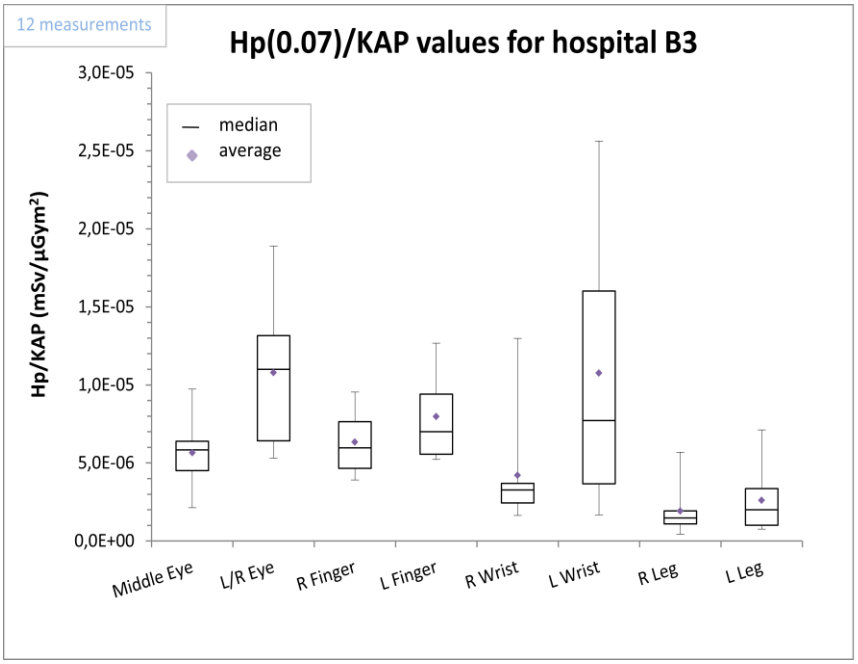


room protective equipment:
table and ceiling

tube configuration: below

various embolisation types
(mostly neuro embolisations)

mostly in the room during
image acquisitions

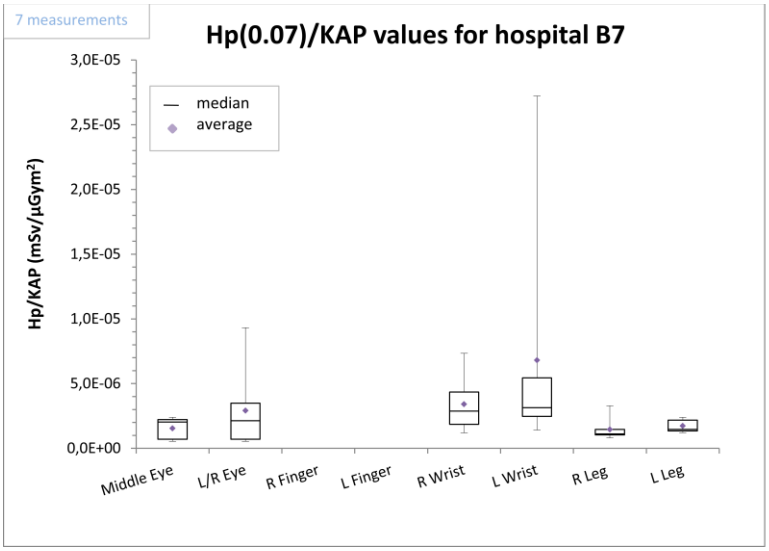


room protective equipment:
table and ceiling (covered only one
tube in biplane technique)

tube configuration:
below for chemoembolisations,
biplane for brain embolisations

various embolisation types (4 liver
chemoembolisations, 8 brain
embol.)

IN the room during image
acquisitions

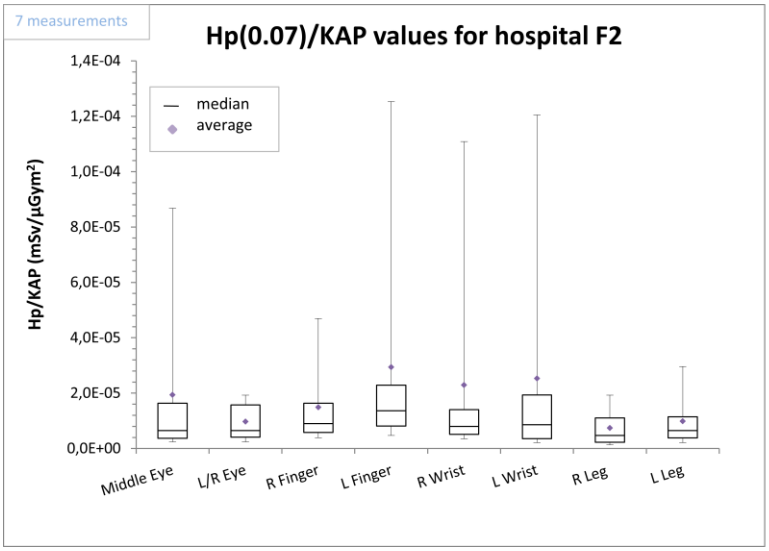


room protective equipment:
table and ceiling

tube configuration: below

various embolisation types (liver chemoembolisations, brain embol., hemorrhages)

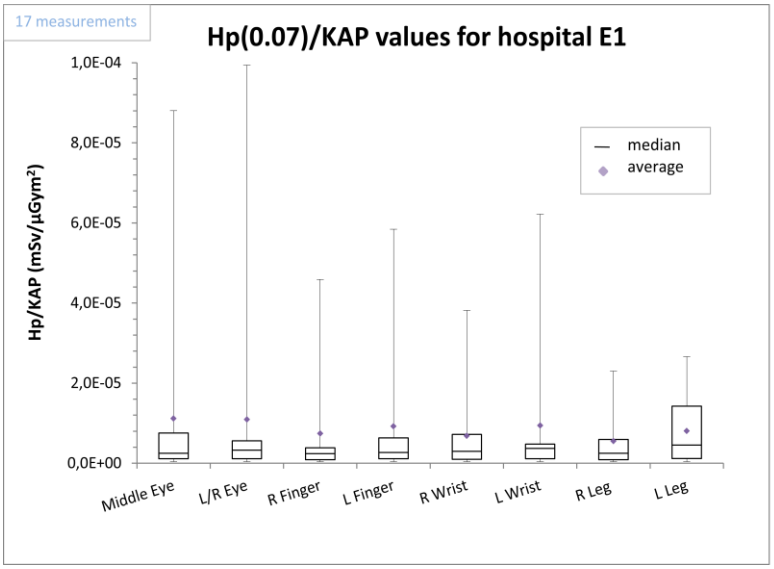
IN the room during image acquisitions



room protective equipment:
table and ceiling

tube configuration: below

IN the room during image acquisitions

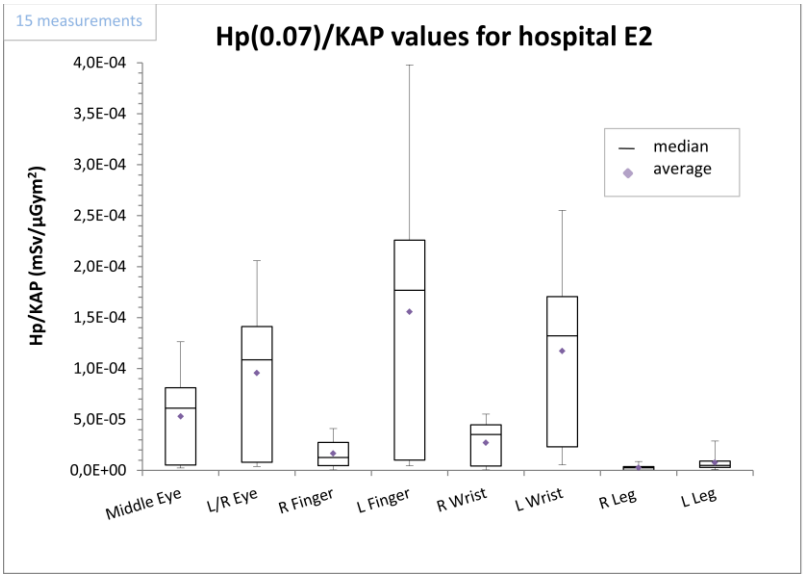


room protective equipment:
table and ceiling

tube configuration: below

neuro embolisations

8 in the room during image acquisitions, 9 out

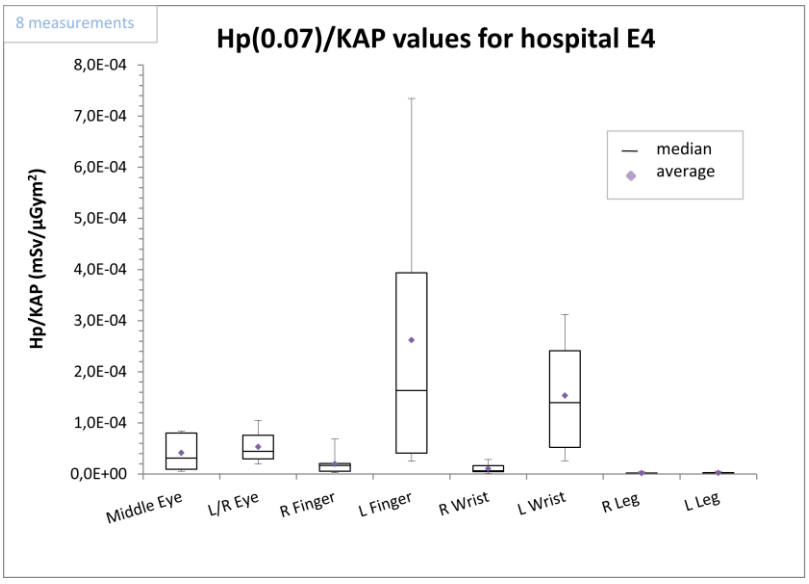


room protective equipment: none

tube configuration: 10 above (image intensifier attached to the table), 5 below

10 embolisations of vena spermatica, 5 chemoembolisations

IN the room during image acquisitions

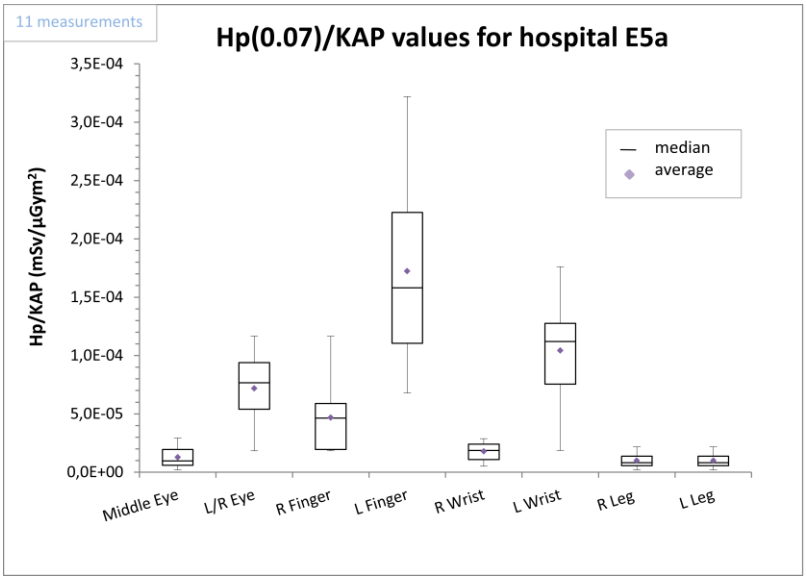


room protective equipment: none (image intensifier attached to the table)

tube configuration: above

embolisations of the abdominal area

IN the room during image acquisitions

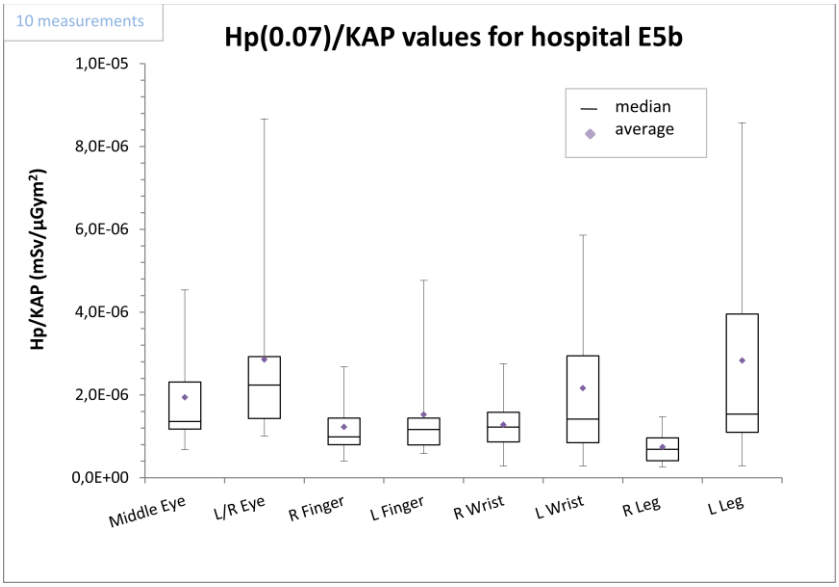


room protective equipment: none

tube configuration: above (image intensifier attached to the table)

10 embolisations of vena spermatica/ovaria

IN the room during image acquisitions

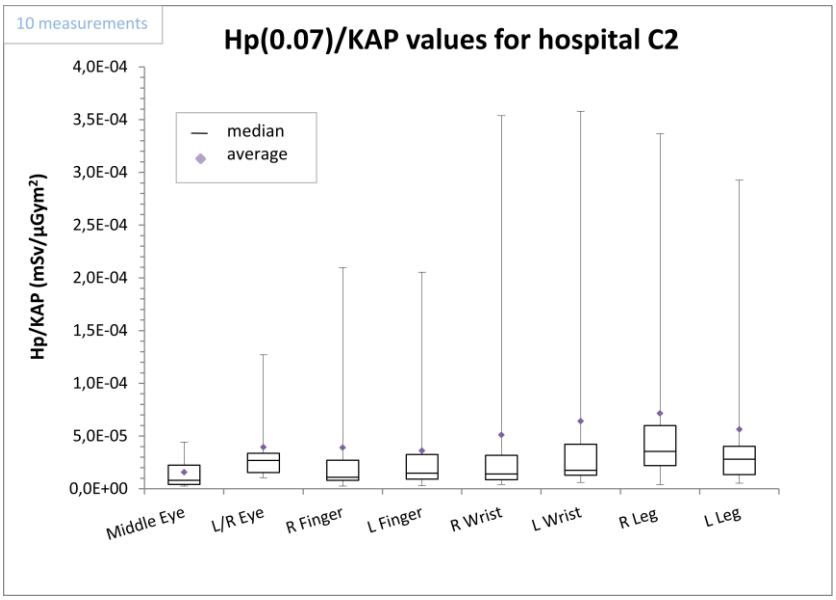


room protective equipment:
table and ceiling

tube configuration:
below

10 neuro embolisations

Sometimes out of the room during image acquisitions

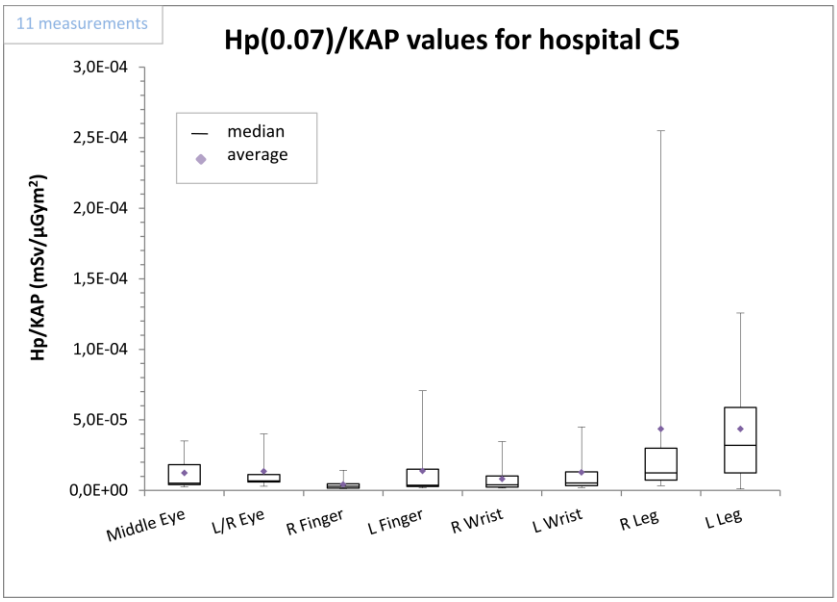


room protective equipment:
Only table

tube configuration:
below

Liver chemoembolisations

OUT of the room during image acquisitions



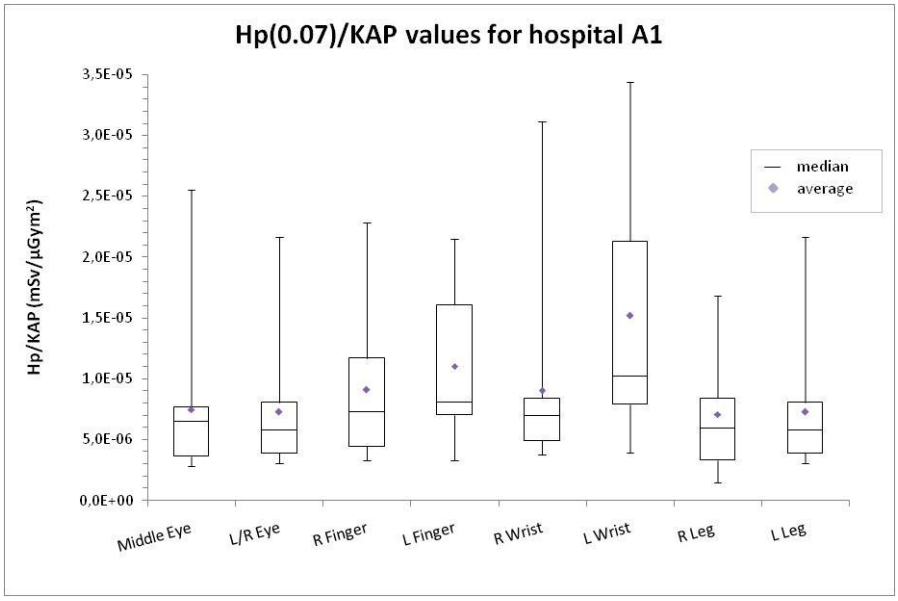
room protective equipment:
none

tube configuration:
below

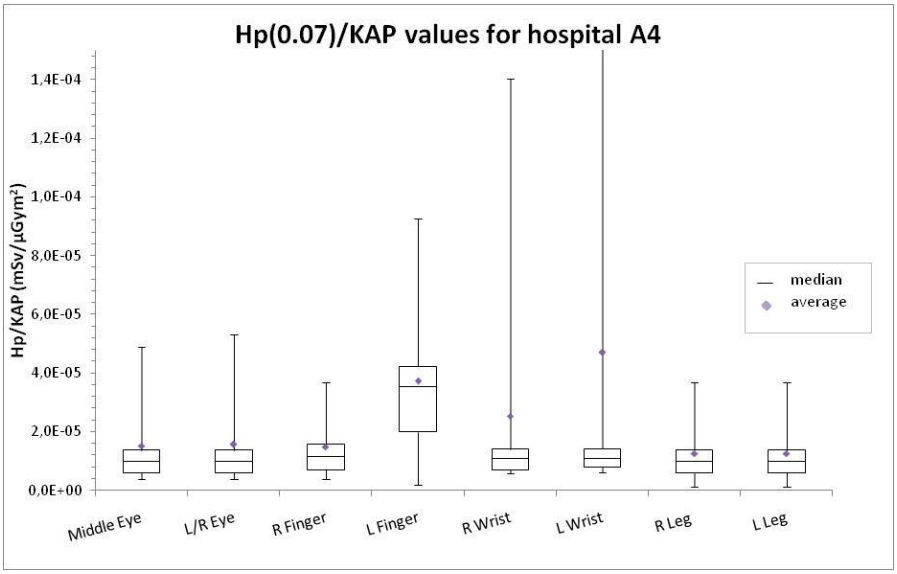
Liver chemoembolisations

OUT of the room during image acquisitions

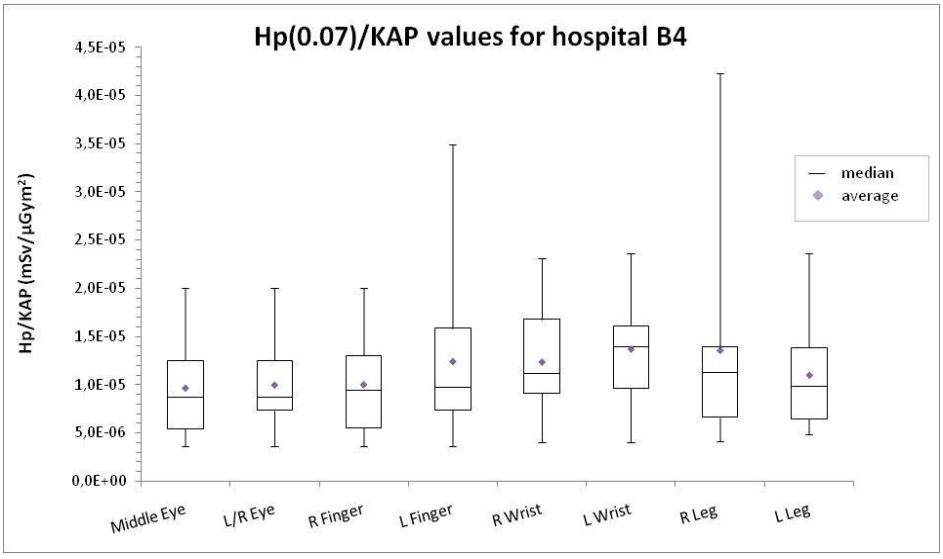
6. Cardiac angiographies (CA) and angioplasties (PTCA)



Number of procedures: 16
tube below
access femoral
shield table

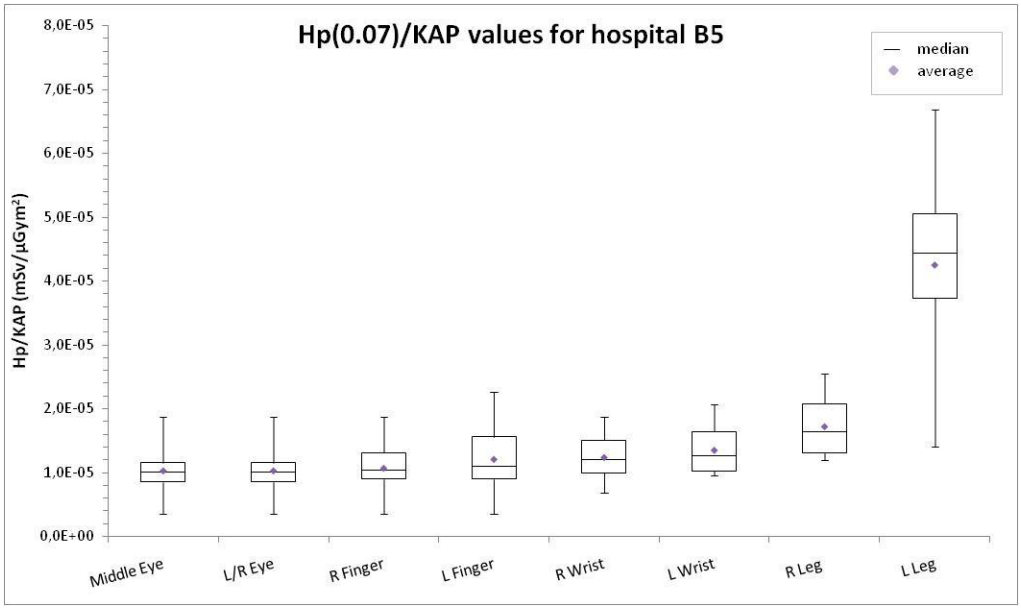


Number of procedures: 10
tube below
access radial
shield table+ceiling

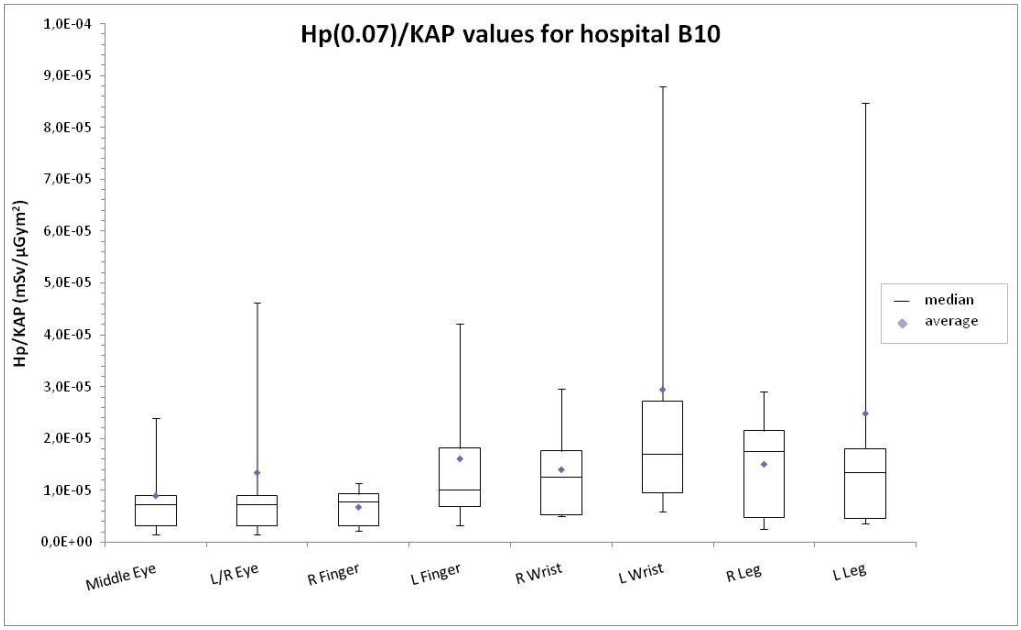


Number of procedures: 13
tube below
access femoral
shield table+ ceiling

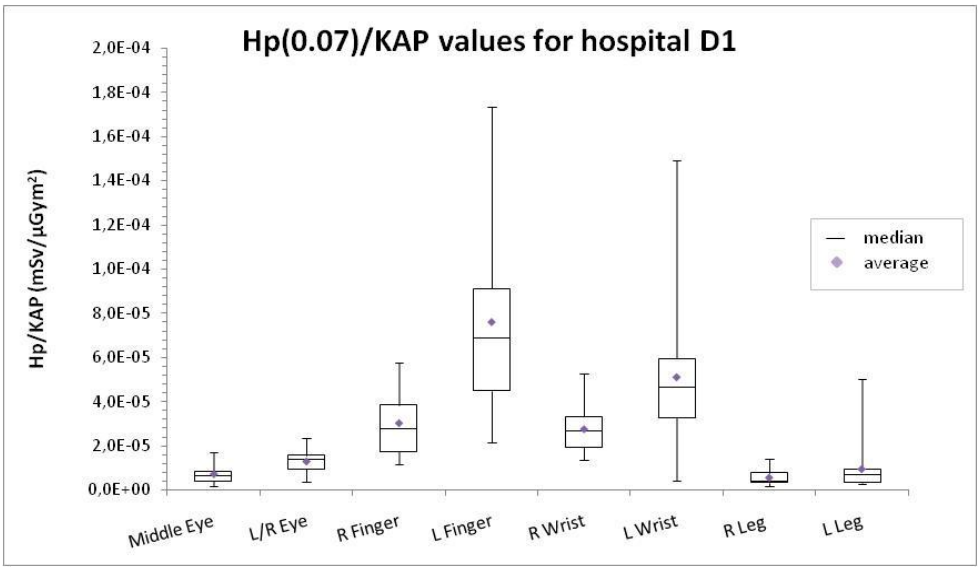
APPENDIX 1



Number of procedures: 12
tube below
access femoral
shield table+ceiling (2), ceiling(10)

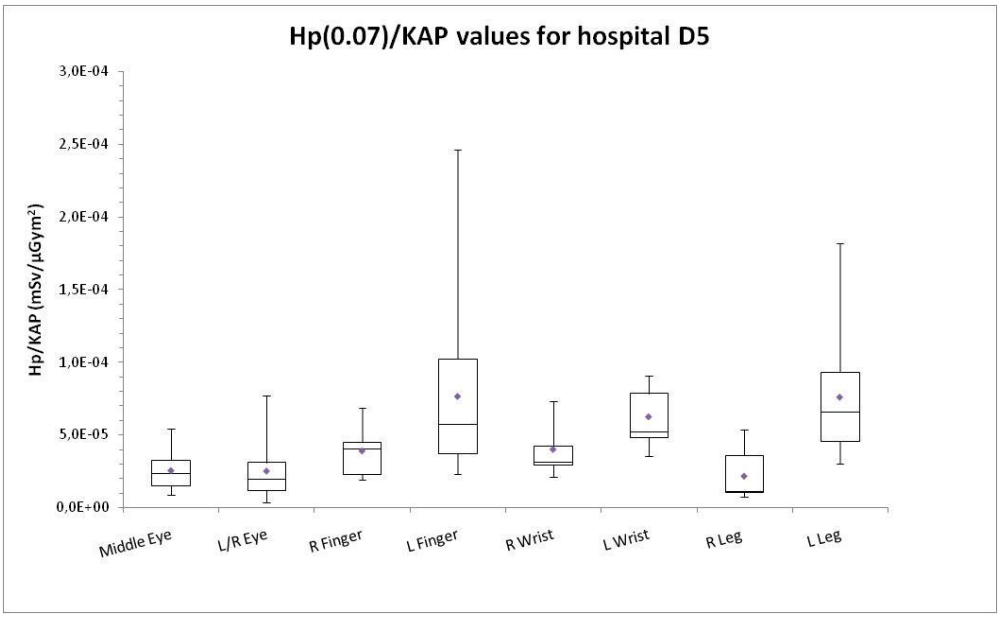


Number of procedures: 5
tube below
access femoral (3), radial (2)
shield table+ceiling

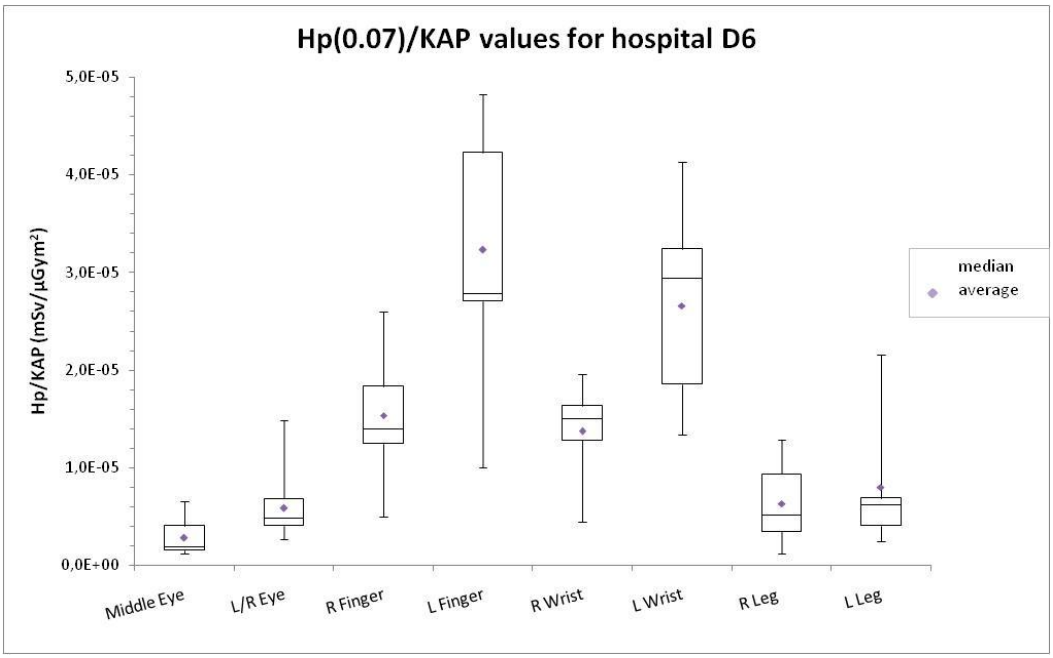


Number of procedures: 15
tube below
access radial
shield table+ceiling

APPENDIX 1

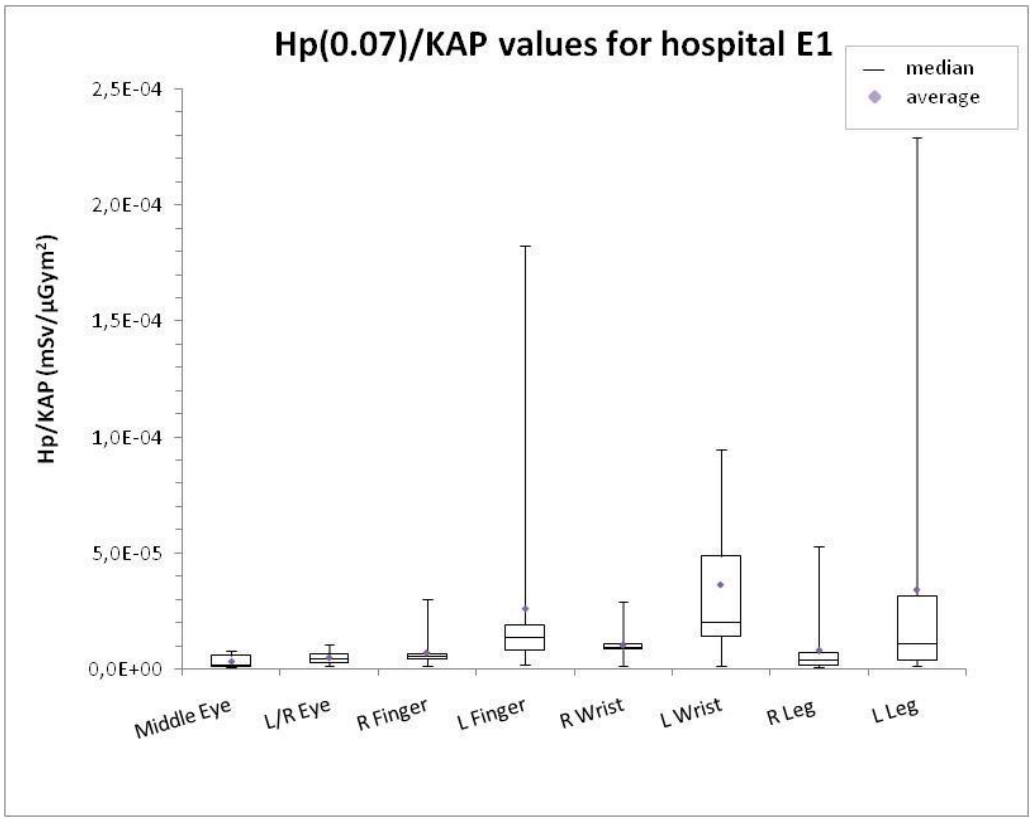


Number of procedures: 15
tube below
access radial
shield table

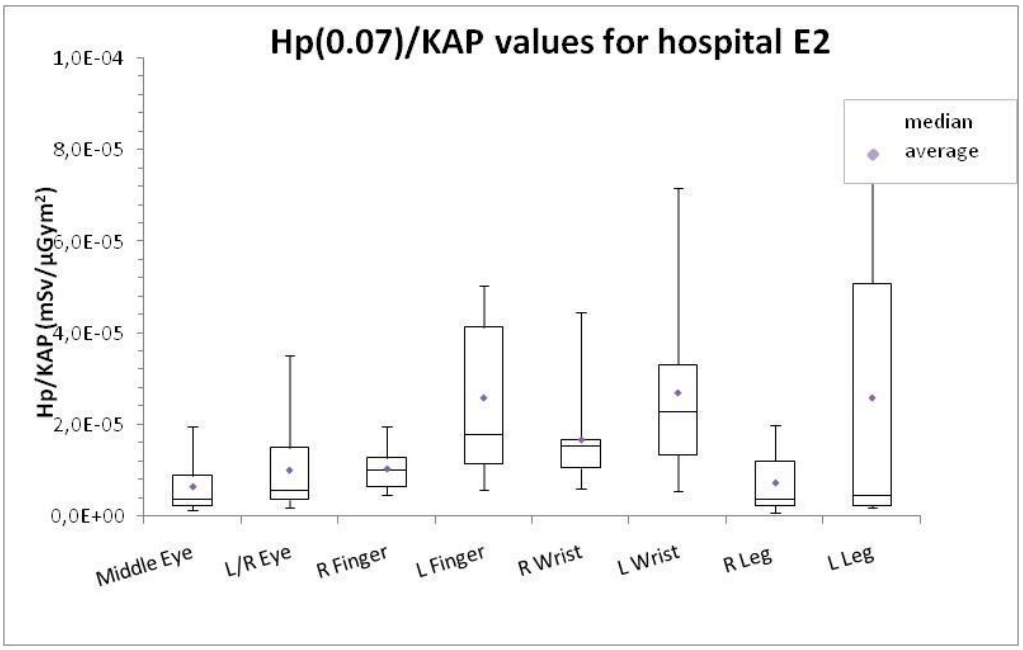


Number of procedures: 10
tube below
access radial (9), femoral (1)
shield table+ceiling (4), table(4), none (1), unknown(1)

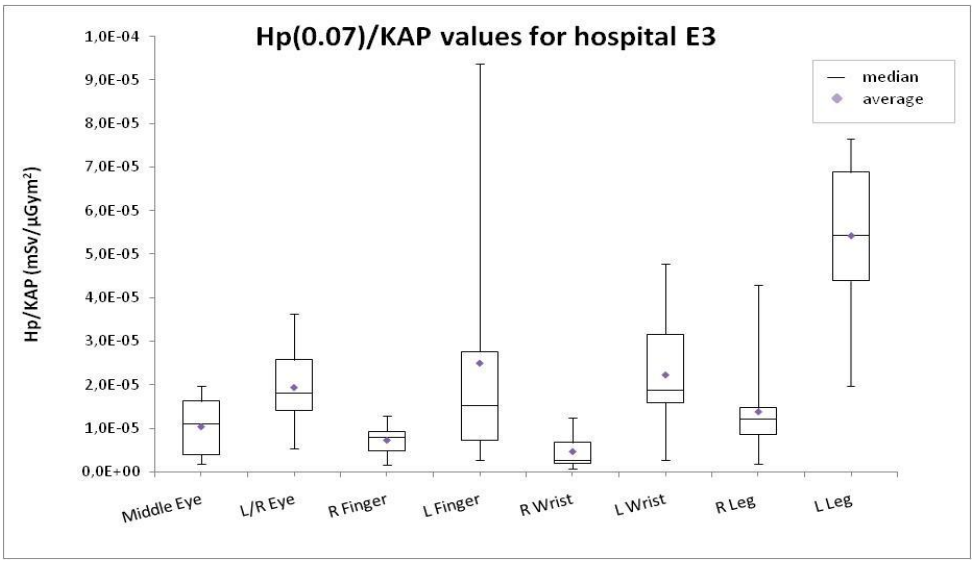
APPENDIX 1



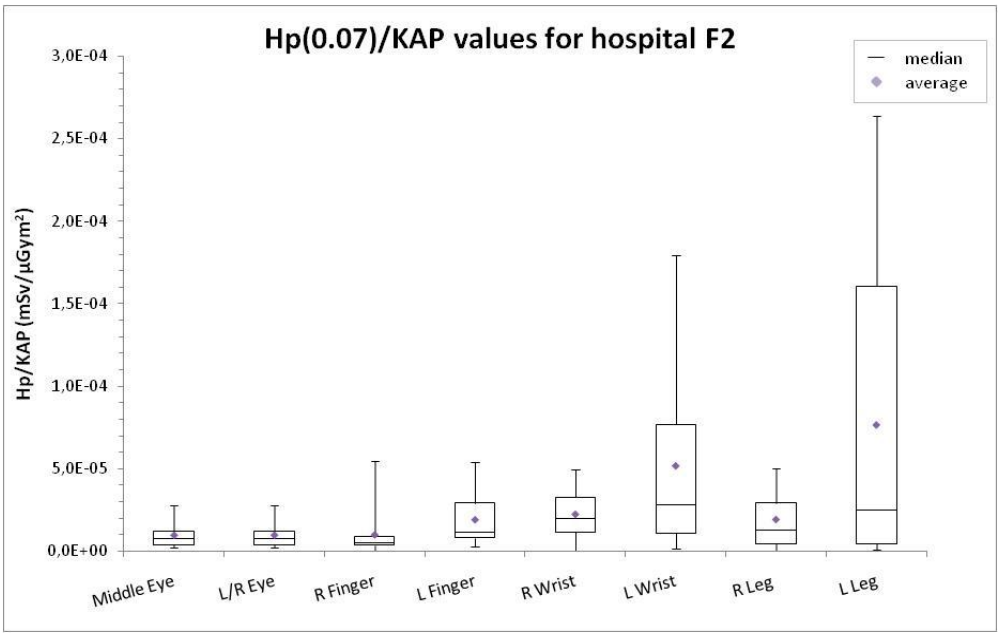
Number of procedures: 13
tube biplane
access femoral
shield table+ceiling



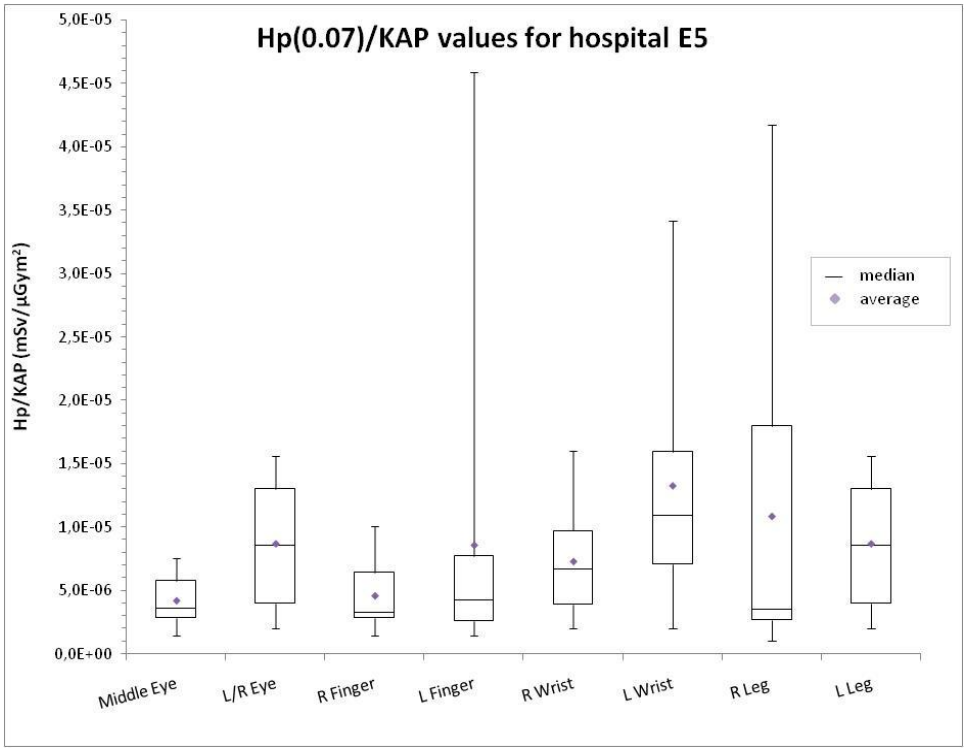
Number of procedures: 11
tube below (4), biplane (7)
access femoral (10), radial (1)
shield table+ceiling (5), table+patient (2), table (1), none (2)



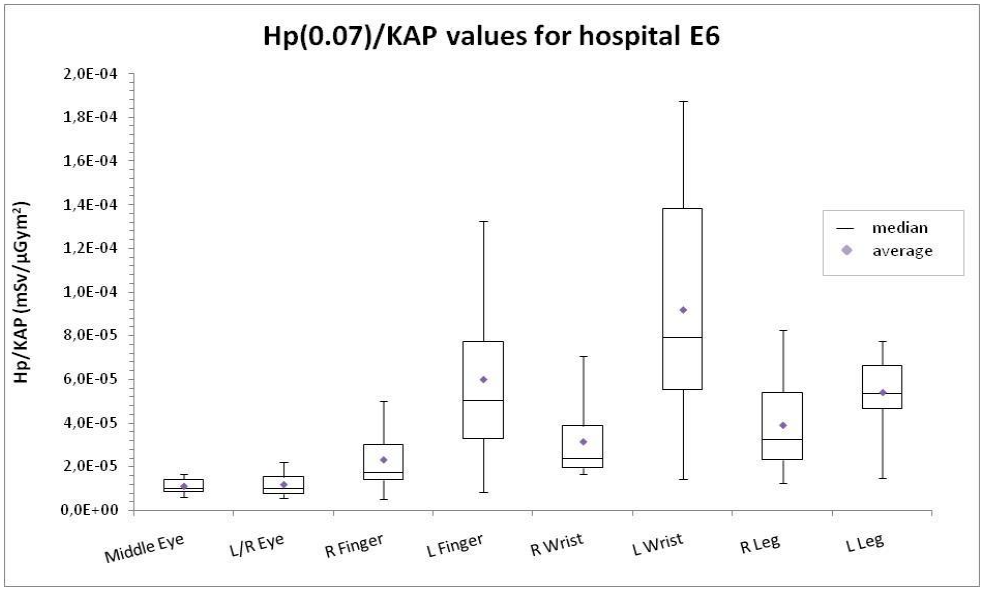
Number of procedures: 10
tube below
access femoral
shield none



Number of procedures: 24
tube below
access femoral (21), radial (3)
shield table+ceiling

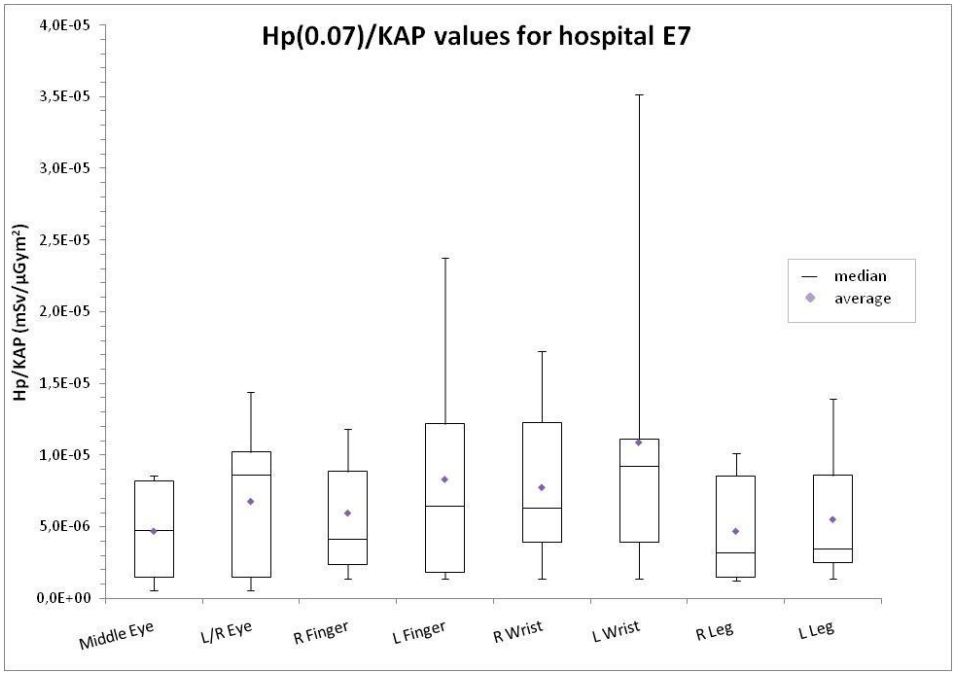


Number of procedures: 10
tube below
access femoral
shield table (4), none (6)

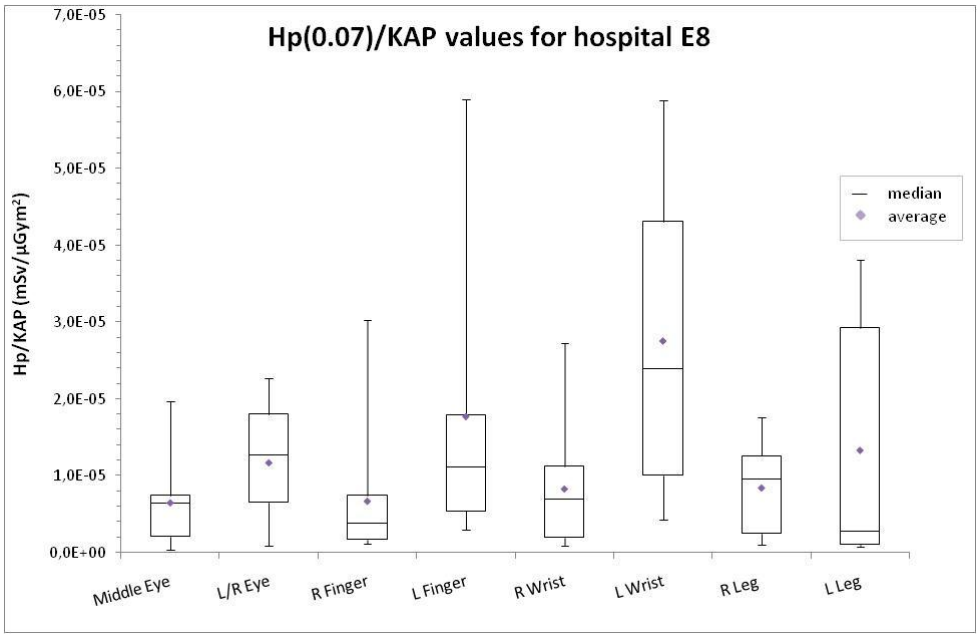


Number of procedures: 10
tube below
access femoral
shield table+ceiling

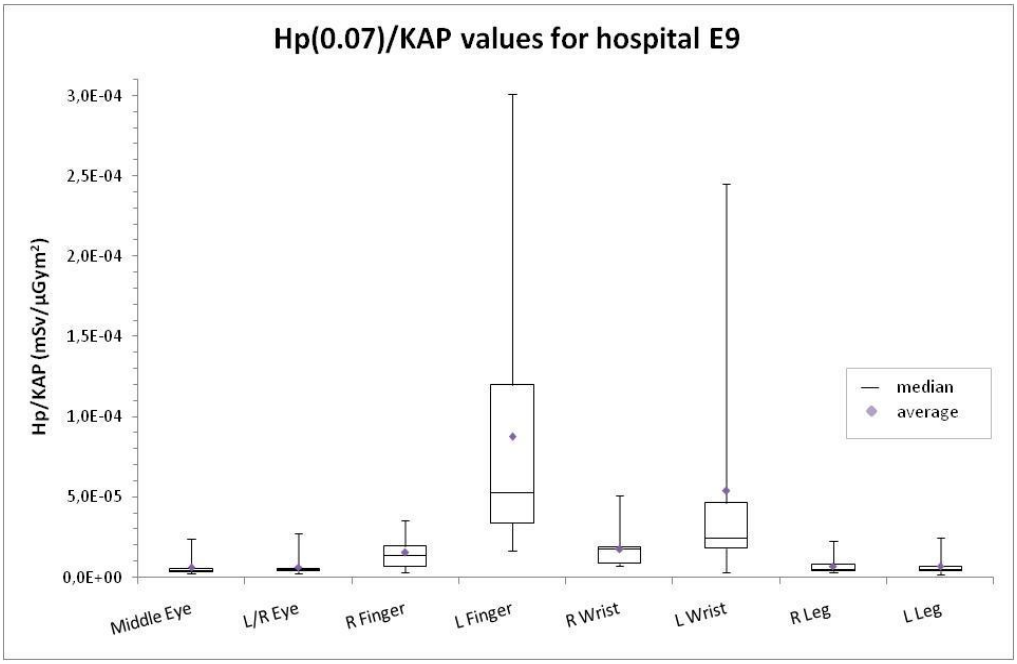
APPENDIX 1



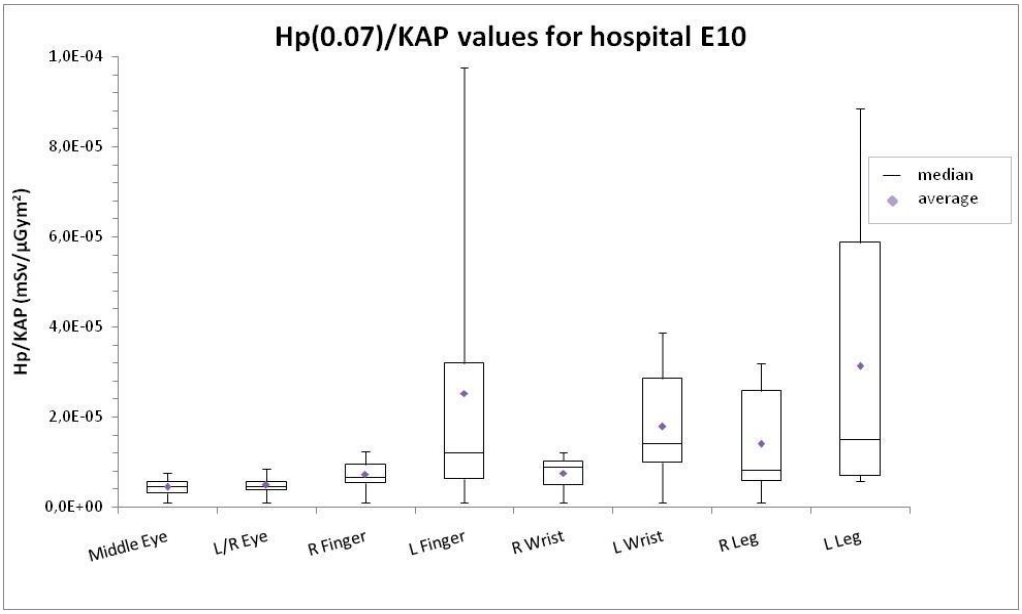
Number of procedures: 9
tube below
access femoral
shield table+ceiling



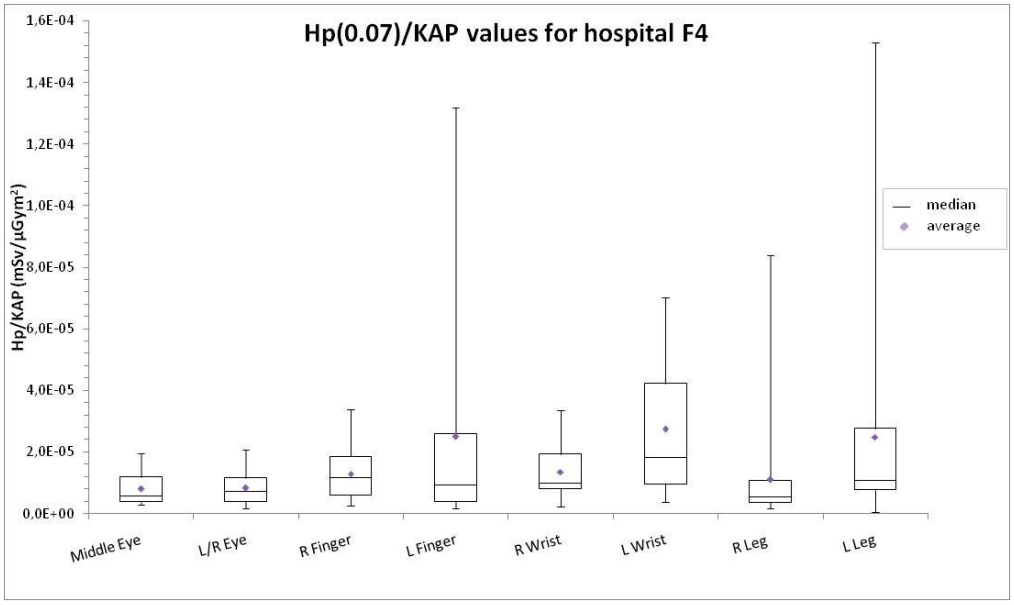
Number of procedures: 10
tube biplane
access femoral (7), radial (3)
shield table+ceiling+floor (2), table+ceiling (1), table (7)



Number of procedures: 13
tube below
access femoral (3), radial (10)
shield table+ceiling

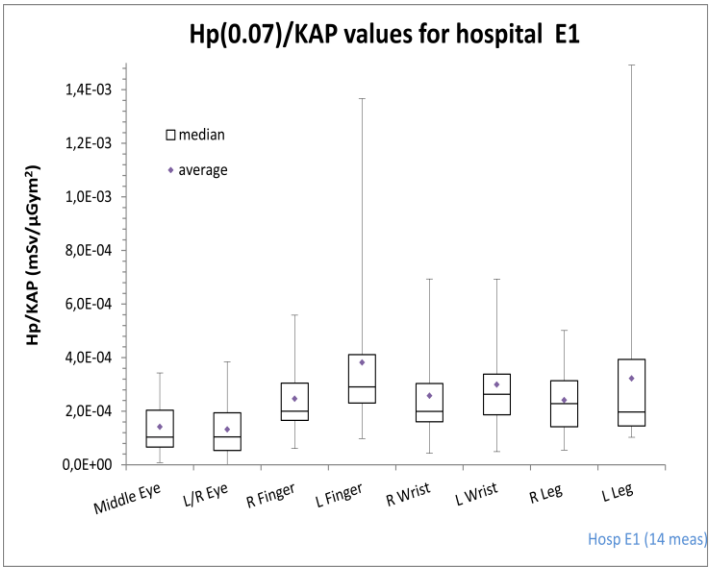


Number of procedures: 10
tube below
access femoral (8), radial (2)
shield table+ceiling



Number of procedures: 17
tube below
access femoral (15), radial (2)
shield table + ceiling

7. Pace makers



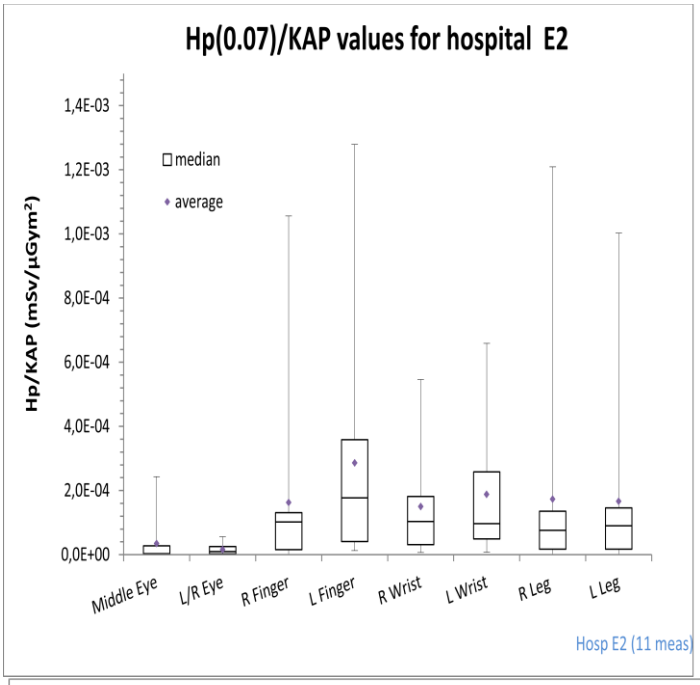
Parameters from the database for this hospital:

Room: none protection equipement

Tube configuration: all measurements have the tube below

Higher dose value is at L leg, but median doses are higher for L-finger

APPENDIX 1

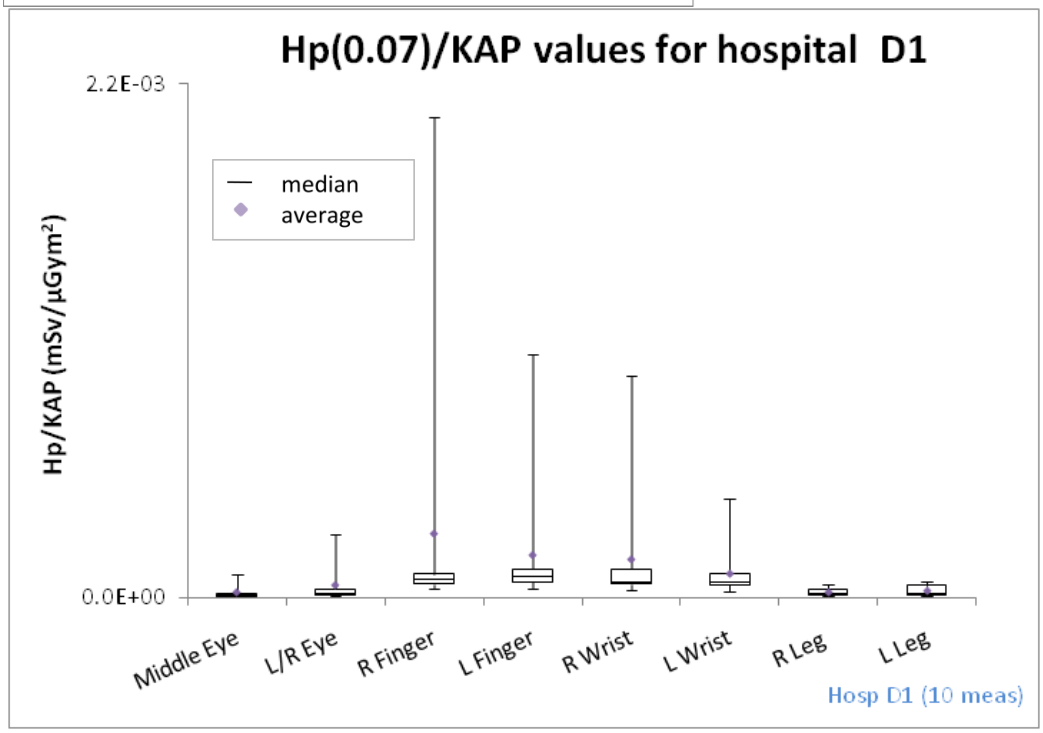


Parameters from the database for this hospital:

Room: none protection equipement

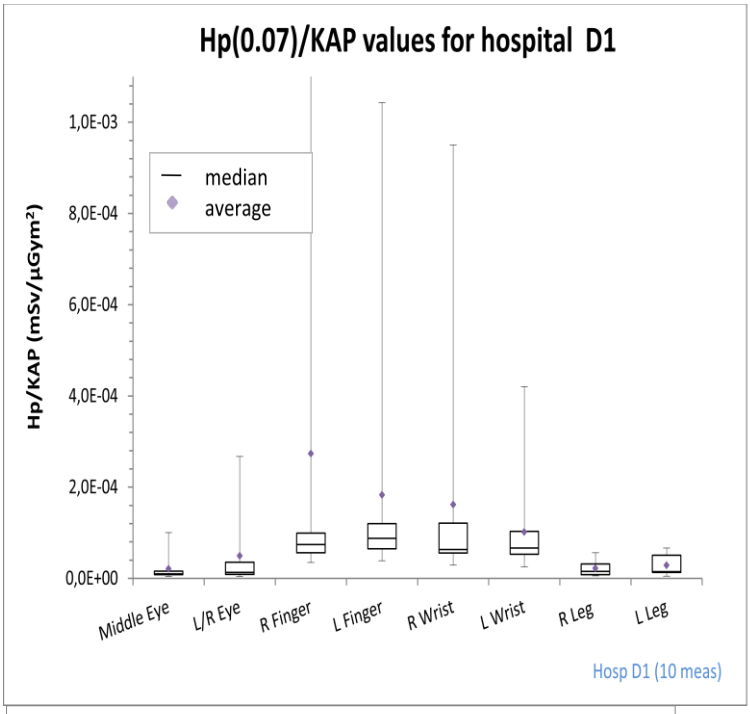
Tube configuration: all measurements have the tube below

Median doses are higher for L-finger



ZOOM

APPENDIX 1

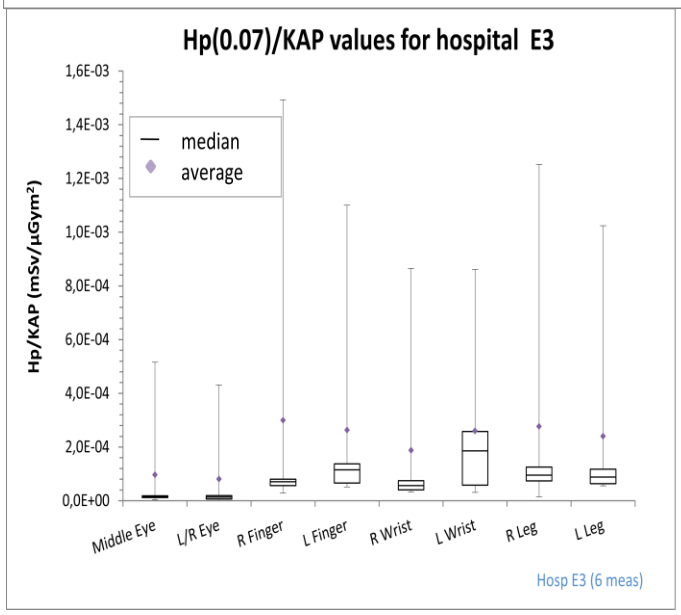


Parameters from the database for this hospital:

Room: several measurements have been done with table's protection

Tube configuration: all measurements have the tube below

Higher dose value is at R finger, but median doses are higher for L-finger



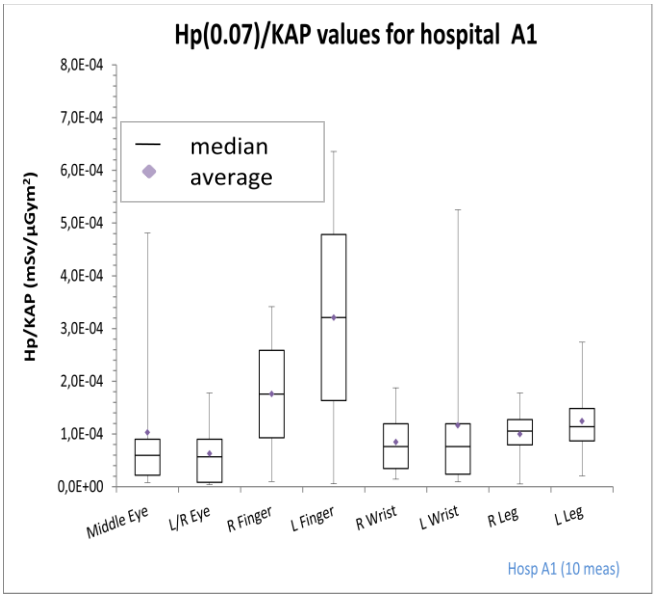
Parameters from the database for this hospital:

Room: none protection equipement

Tube configuration: all measurements have the tube below

Higher dose value is at R finger, but median doses are higher for L-Wrist

APPENDIX 1

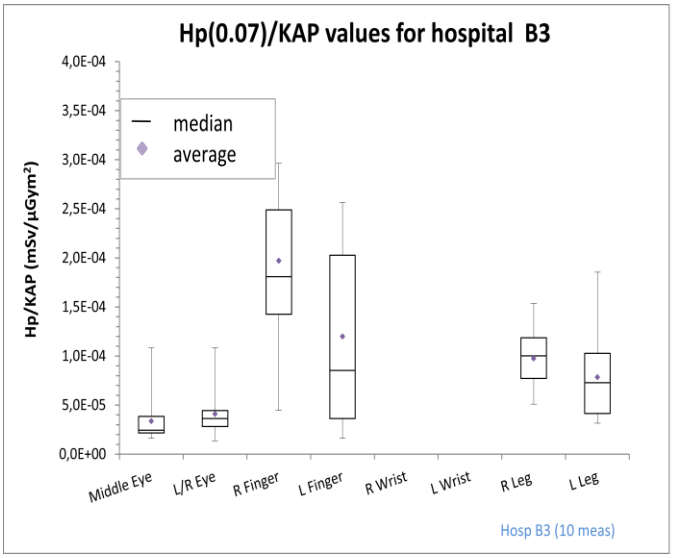


Parameters from the database for this hospital:

Room: 20% of measurement have been done with table protection, 20% with table+ceiling and 60% none protection equipement

Tube configuration: all measurements have the tube below

Median doses are higher for L-finger

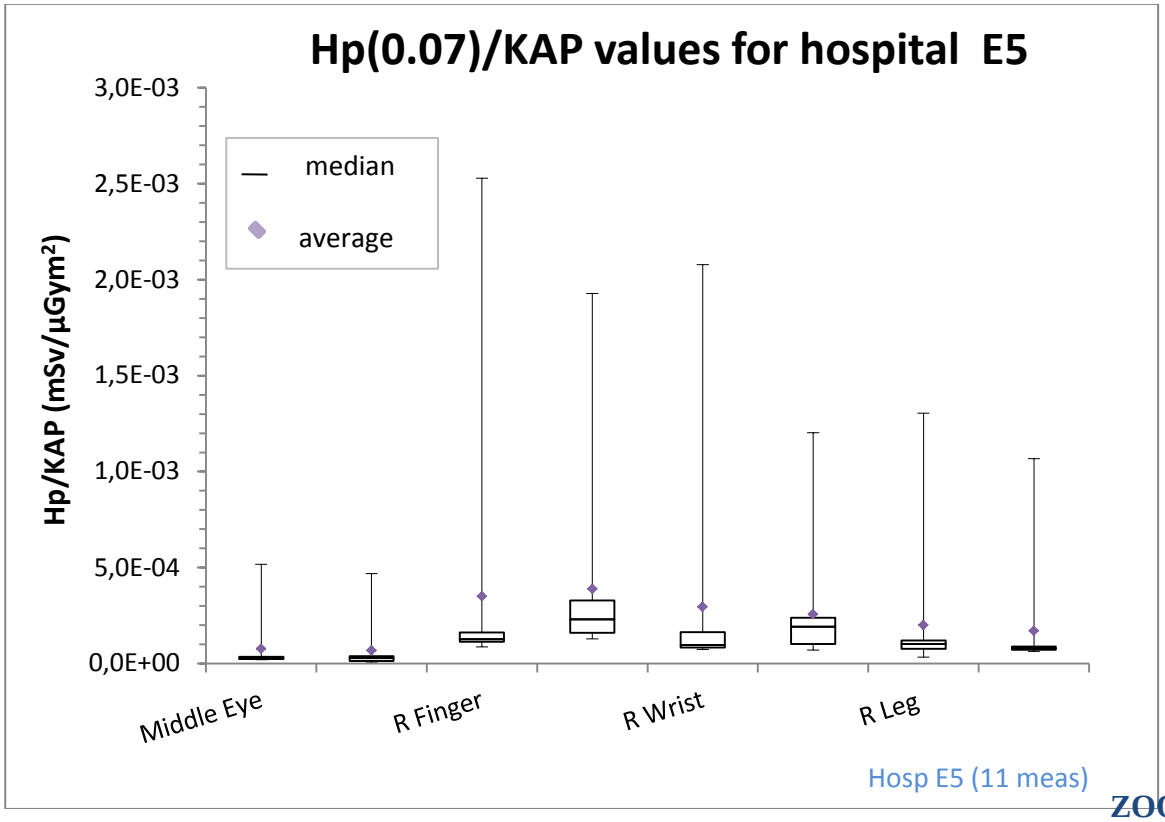


Parameters from the database for this hospital:

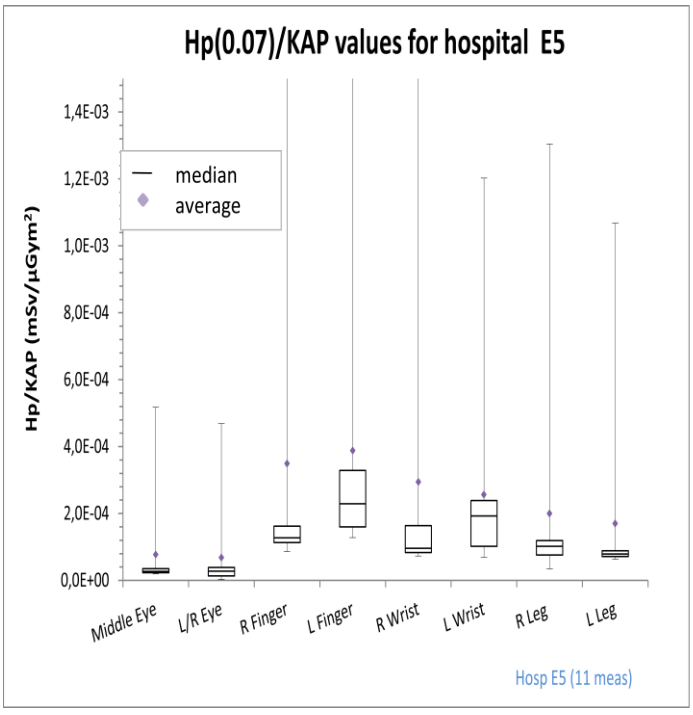
Room: 20% of measurement have been done with table protection, and 80% without protection equipement.

Tube configuration: all measurements have the tube below

Median doses are higher for R-finger



ZOOM

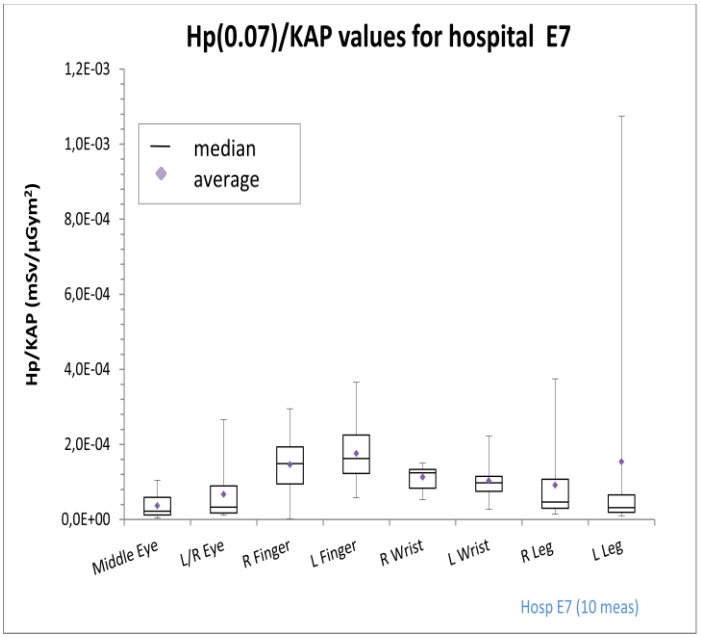


Parameters from the database for this hospital:

Room: all measurements have been done without protection equipement.

Tube configuration: all measurements have the tube below

Higher dose value is at R finger, but median doses are higher for L-Wrist

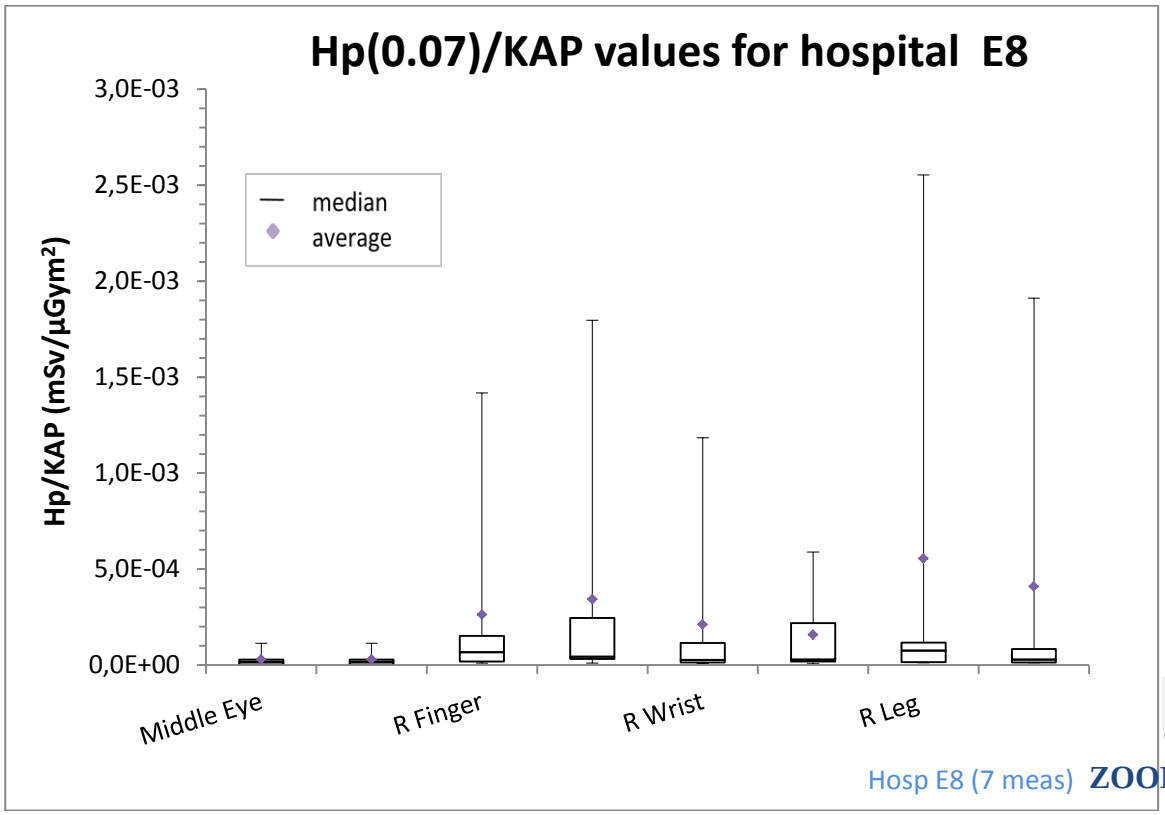


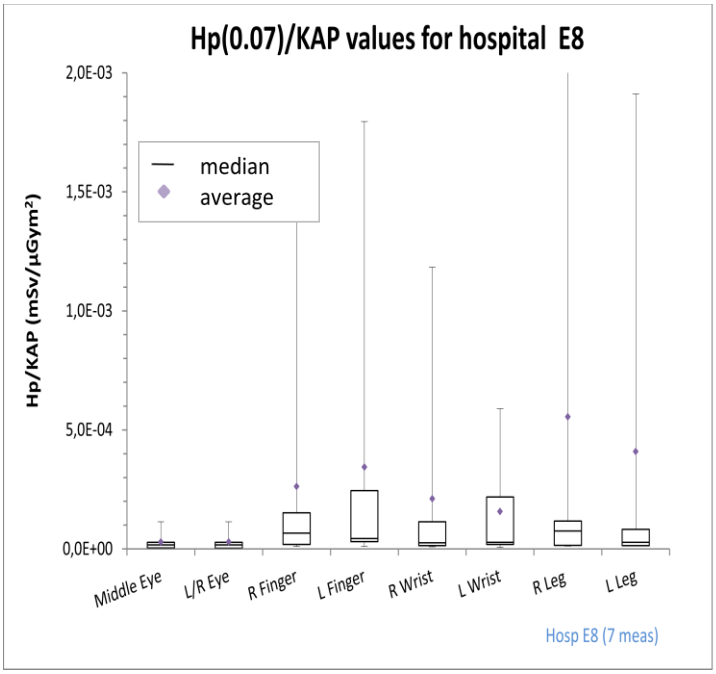
Parameters from the database for this hospital:

Room: all measurements have been done with protection table, where 20% also added ceiling protection.

Tube configuration: all measurements have the tube below

Median doses are higher for L-finger
In 20% of measurements, hands have been seen in the FOV



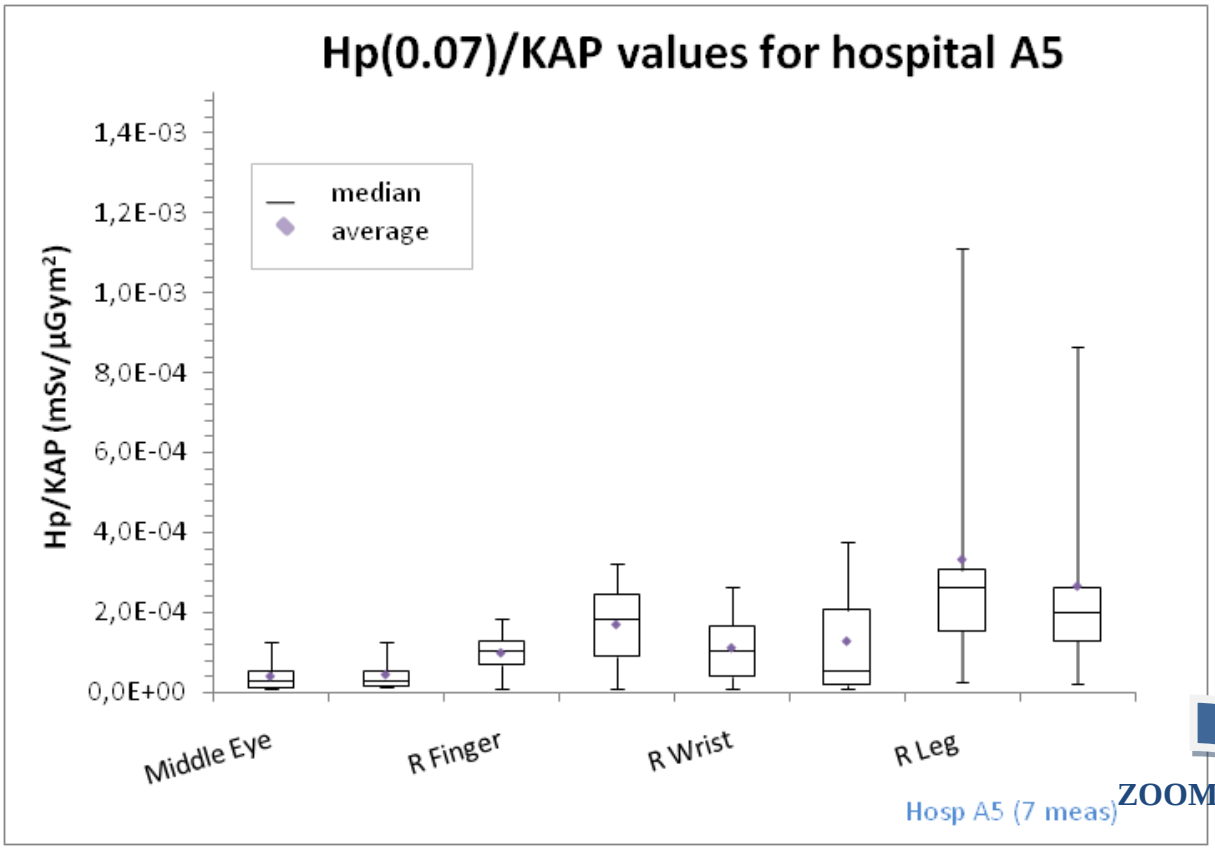


Parameters from the database for this hospital:

Room: all measurements have been done without protection equipement

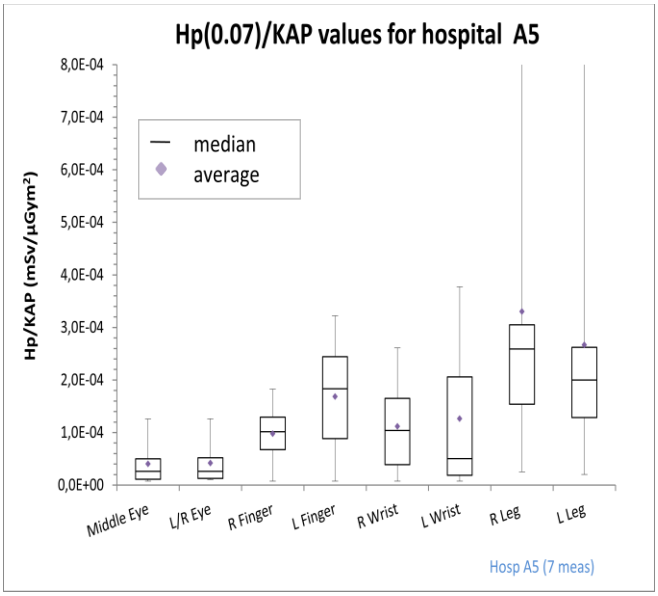
Tube configuration: all measurements have the tube below

Median and maximum doses are higher for R-leg



ZOOM

APPENDIX 1

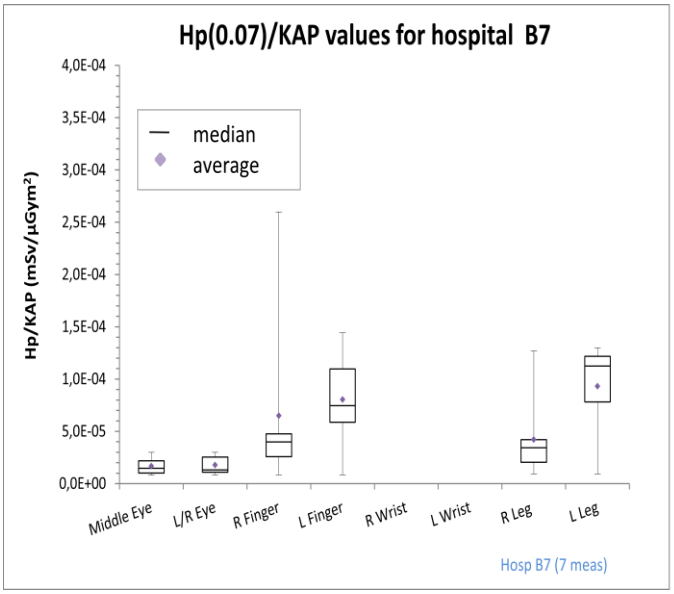


Parameters from the database for this hospital:

Room: 57% of measurements have been done without protection equipement and 43% with table protection.

Tube configuration: all measurements have the tube below

Median and maximum doses are higher for R-leg

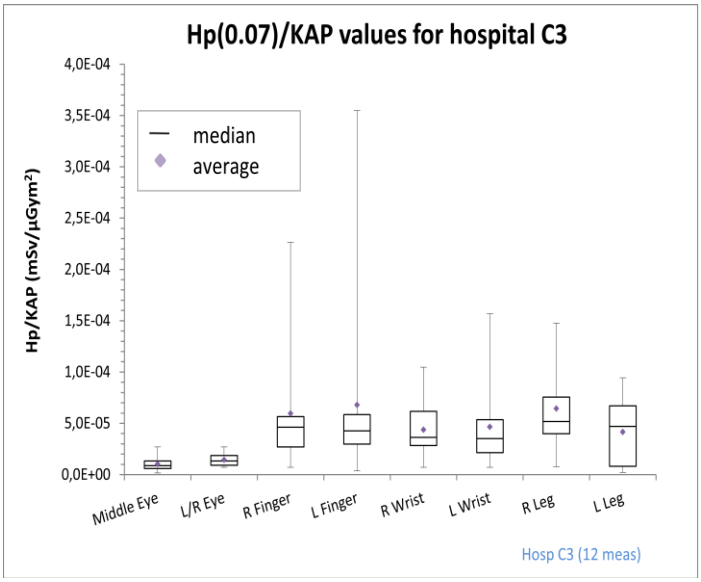


Parameters from the database for this hospital:

Room: 71% of measurements have been done without protection equipement and 29% with table protection.

Tube configuration: all measurements have the tube below

Maximum values doses are higher for R-finger, but median values are higher for L-leg



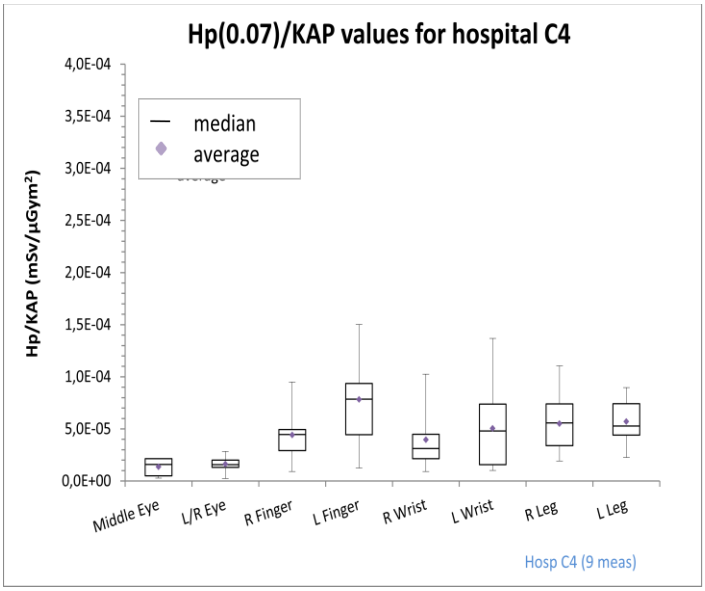
Parameters from the database for this hospital:

Room: 67 % of measurements have been done with table protection, 8% table+ceiling, 8% ceilind and 17% without protection equipment.

Tube configuration: all measurements have the tube below

Maximum values doses are higher for L finger, but median values are higher for Rleg

APPENDIX 1

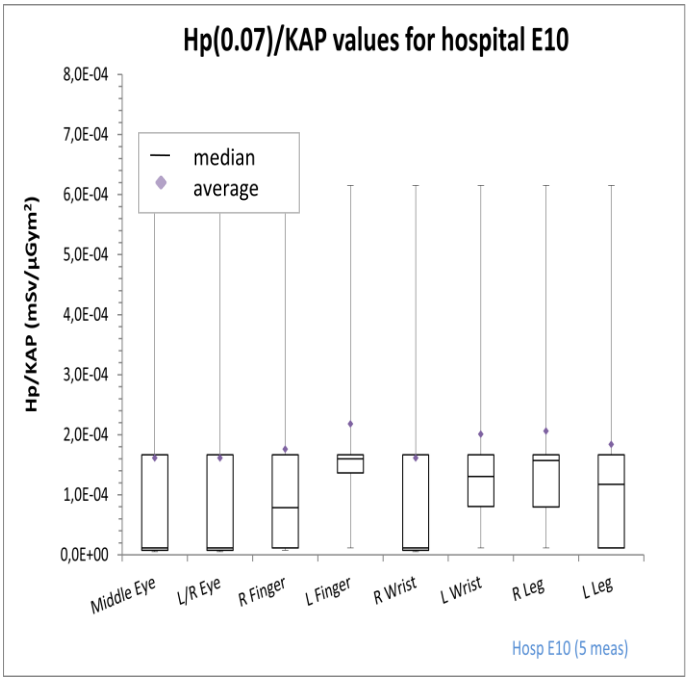


Parameters from the database for this hospital:

Room: any protection equipement.

Tube configuration: all measurements have the tube below

Median and maximum values doses are higher for L-finger



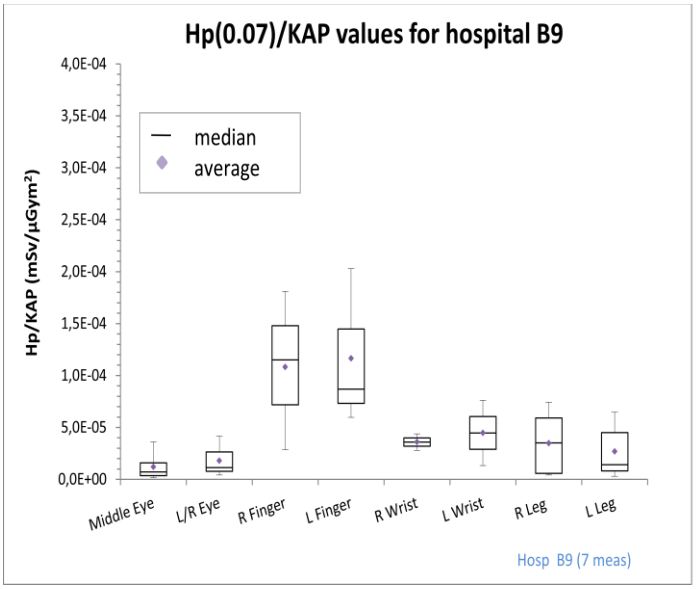
Parameters from the database for this hospital:

Room: all measurements have been done with table protection.

Tube configuration: all measurements have the tube below

When we normalized doses, some measurements have as values the LDL and the respective DAP is also very small (13 and 45mSv/µGym2); so the max doses are always the same value.

Median values doses are higher for L-finger

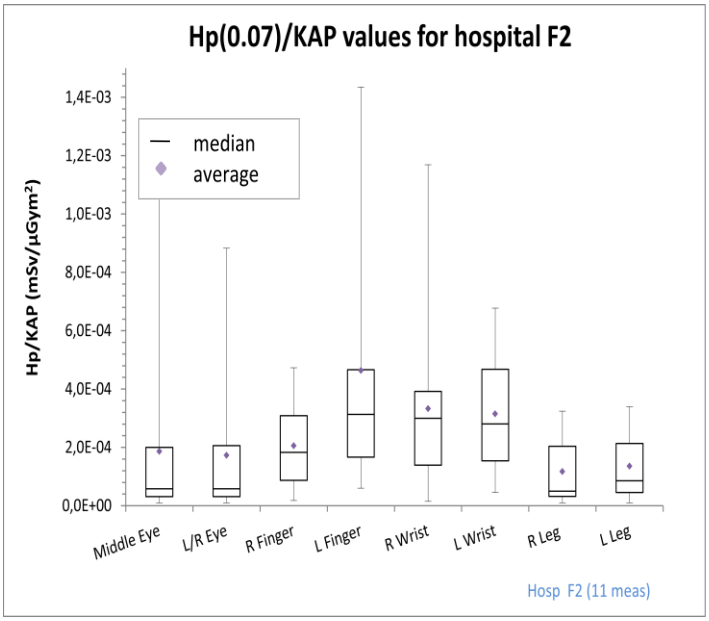


Parameters from the database for this hospital:

Room: 43% of measurements have been done with table protection; 43% without protection and 14% with table and ceiling's protection

Tube configuration: all measurements have the tube below

Maximum values doses are higher for L-finger, but median values doses are higher for R-finger

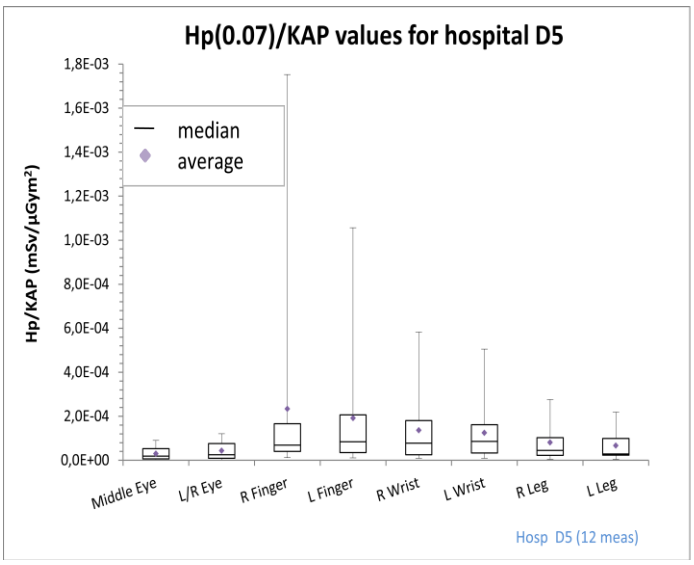


Parameters from the database for this hospital:

Room: 73% of measurements have been done with table+ceiling protection; 18% with table protection and 9% with only ceiling's protection

Tube configuration: all measurements have the tube below

Median and maximum doses are higher for L-finger

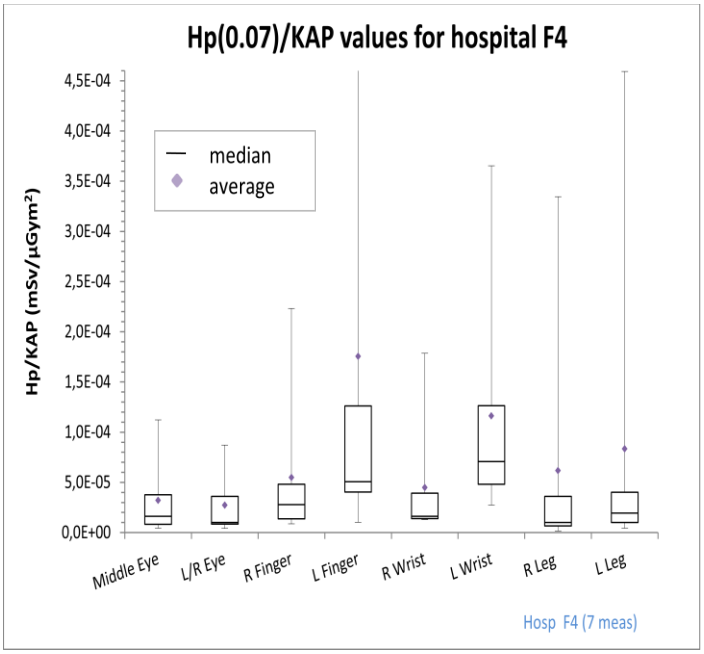


Parameters from the database for this hospital:

Room: all measurements have been done without protection equipement

Tube configuration: all measurements have the tube below

Median and maximum doses are higher for R-finger

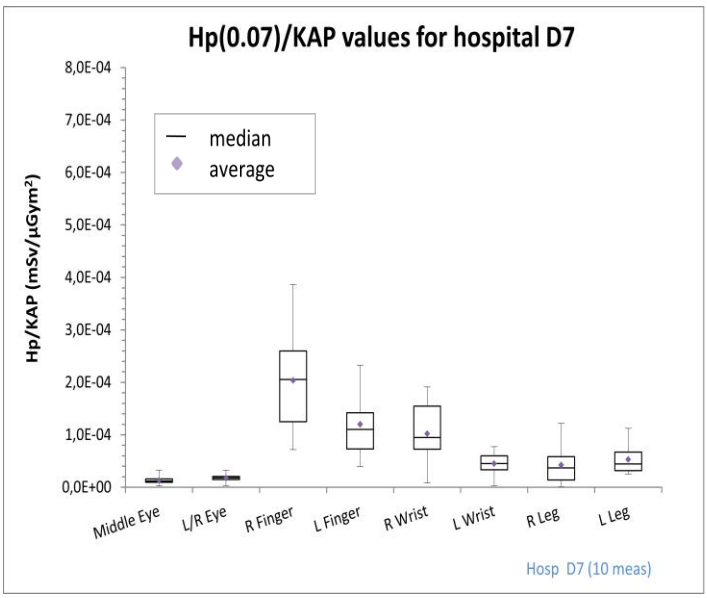


Parameters from the database for this hospital:

Room: 86% of measurements have been donde with table and ceiling protection, and 14% only with table protection

Tube configuration: all measurements have the tube below

Maximum values doses are higher for L-finger, but median values doses are higher for L-wrist

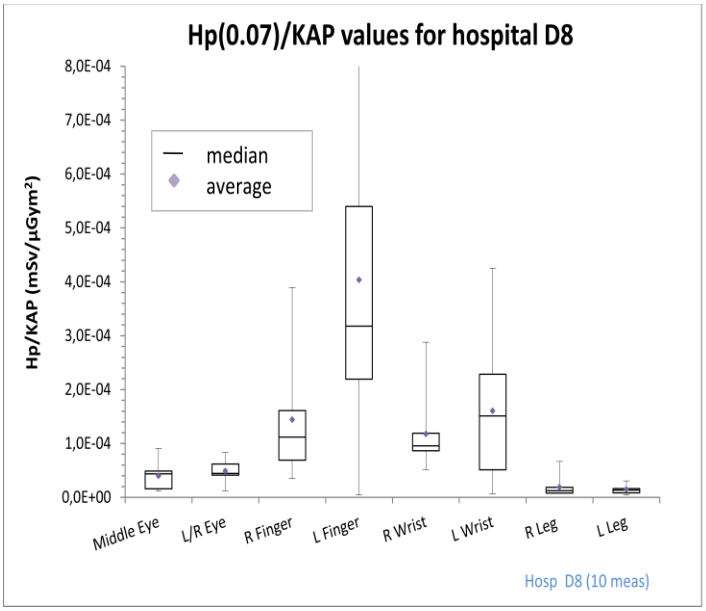


Parameters from the database for this hospital:

Room: no protection equipement

Tube configuration: all measurements have the tube below

Median and maximum doses are higher for R-finger



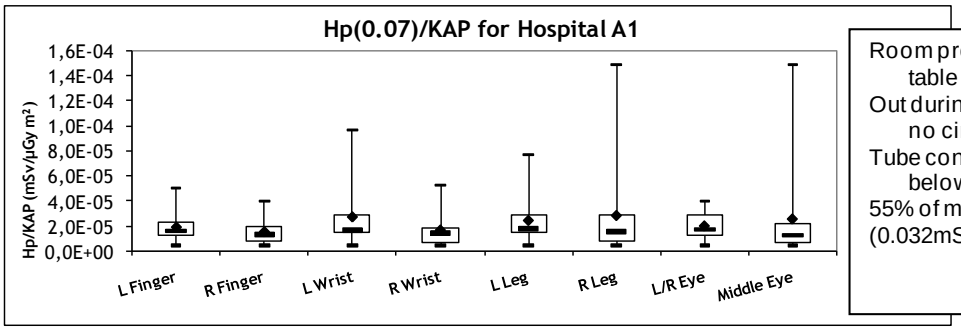
Parameters from the database for this hospital:

Room: no protection equipement

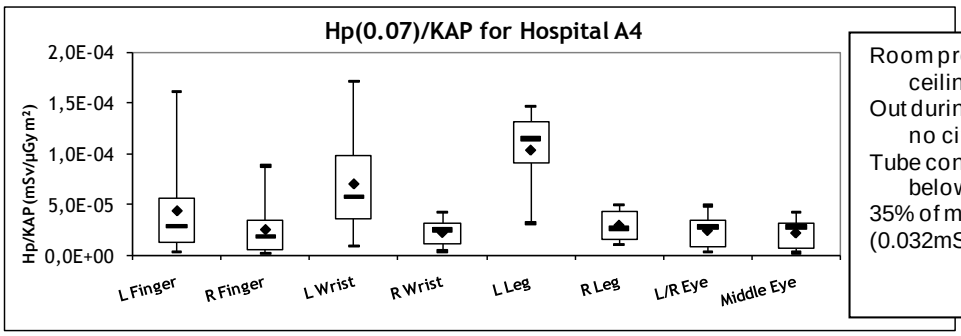
Tube configuration: all measurements have the tube above

Median and maximum doses are higher for L-finger

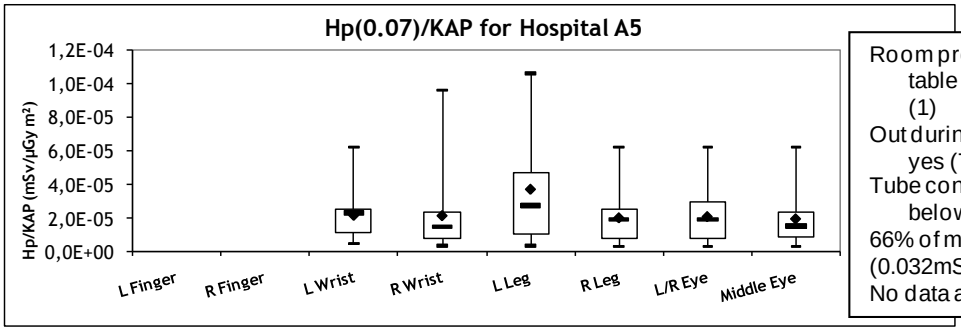
8. RF Ablations



Room protective equipment:
table + ceiling
Out during cine:
no cine
Tube configuration:
below
55% of measurements are LDL (0.032mSv)



Room protective equipment:
ceiling (8), table + ceiling (2)
Out during cine:
no cine
Tube configuration:
below (6), above (4)
35% of measurements are LDL (0.032mSv)



Room protective equipment:
table + ceiling (8), patient (1)
Out during cine:
yes (7), unknown (4)
Tube configuration:
below
66% of measurements are LDL (0.032mSv)
No data at L and R fingers

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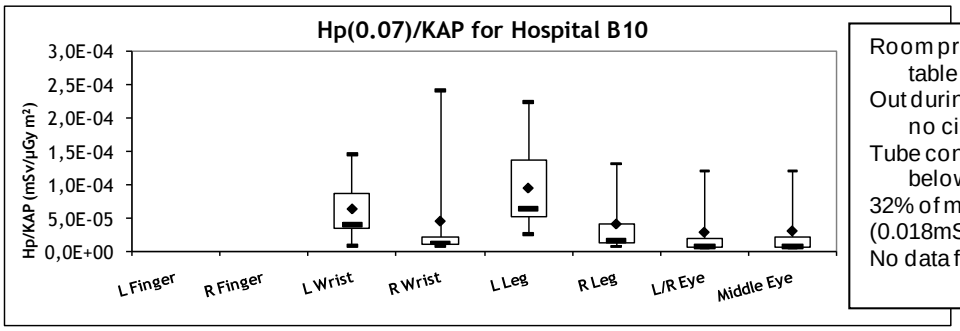
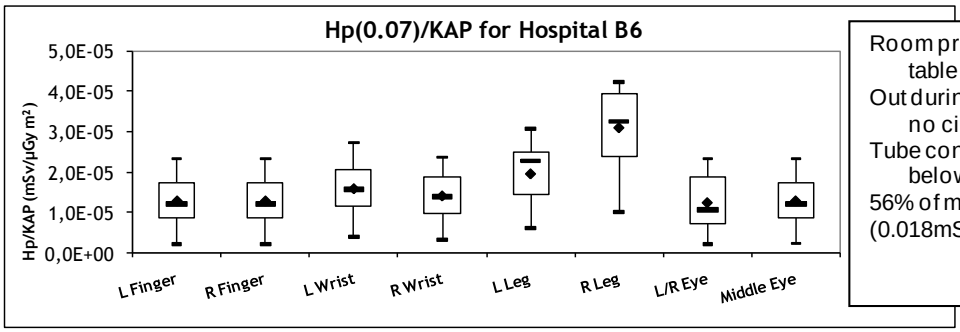
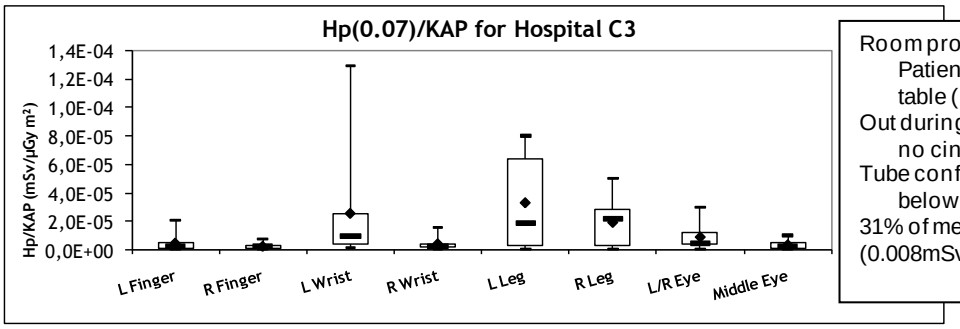


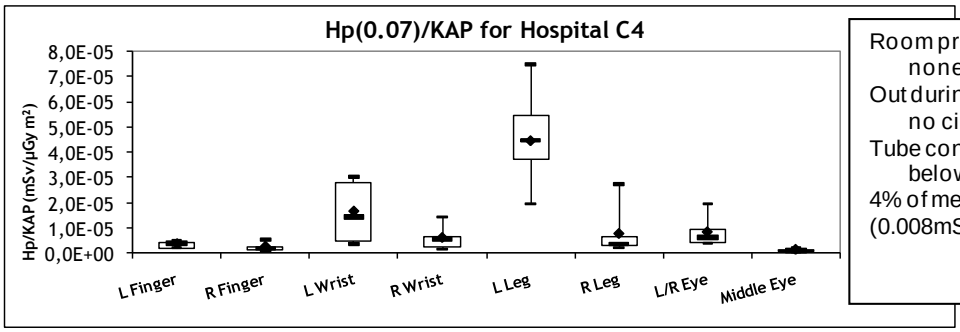
Room protective equipment:
table + ceiling
Out during cine:
no cine
Tube configuration:
below
32% of measurements are LDL (0.018mSv)
No data for L and R fingers



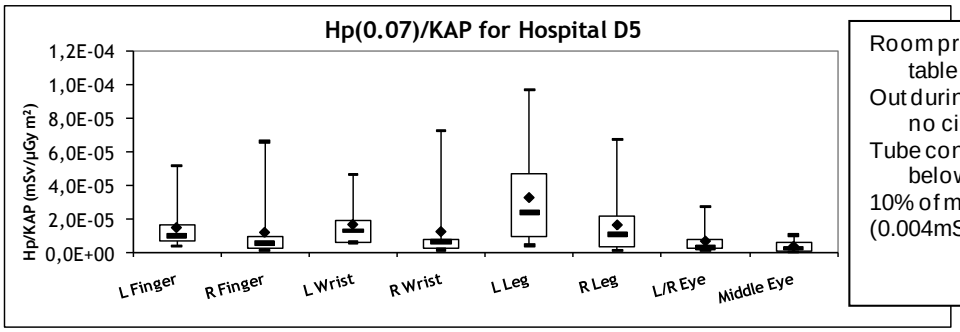
Room protective equipment:
table + ceiling
Out during cine:
no cine
Tube configuration:
below
56% of measurements are LDL (0.018mSv)



Room protective equipment:
Patient(6), table + ceiling (4); table (1), none (2)
Out during cine:
no cine
Tube configuration:
below
31% of measurements are LDL (0.008mSv)



Room protective equipment:
none
Out during cine:
no cine
Tube configuration:
below
4% of measurements are LDL (0.008mSv)



Room protective equipment:
table
Out during cine:
no cine
Tube configuration:
below
10% of measurements are LDL (0.004mSv)

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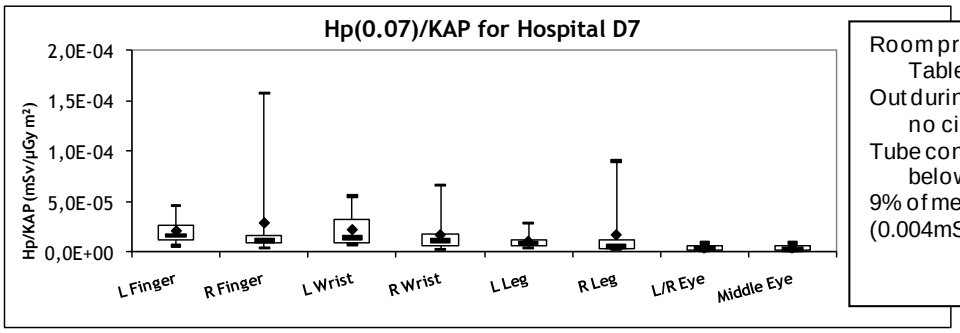
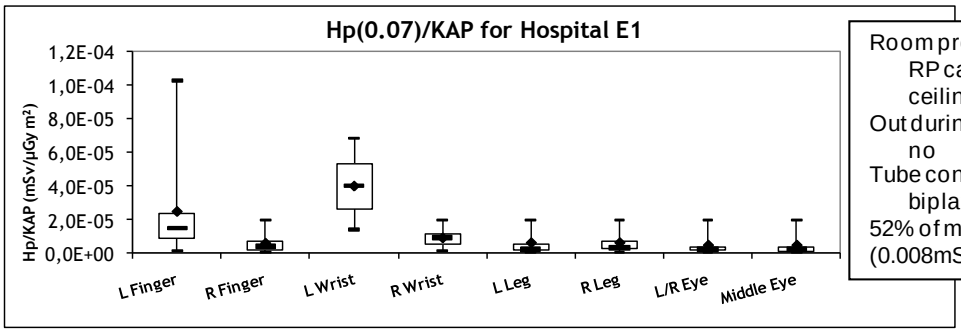
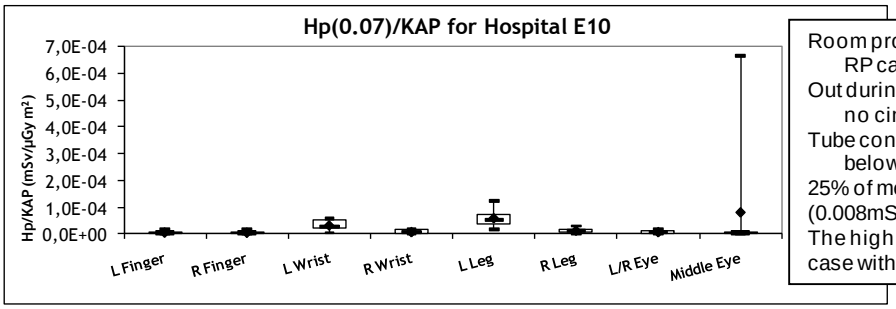


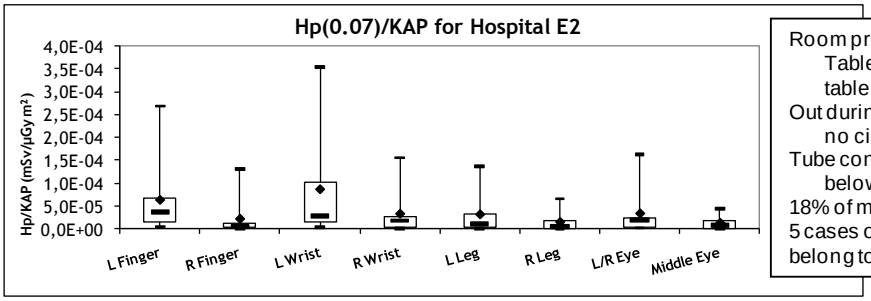
Room protective equipment:
Table (6), table + ceiling (3)
Out during cine:
no cine
Tube configuration:
below
9% of measurements are LDL (0.004mSv)



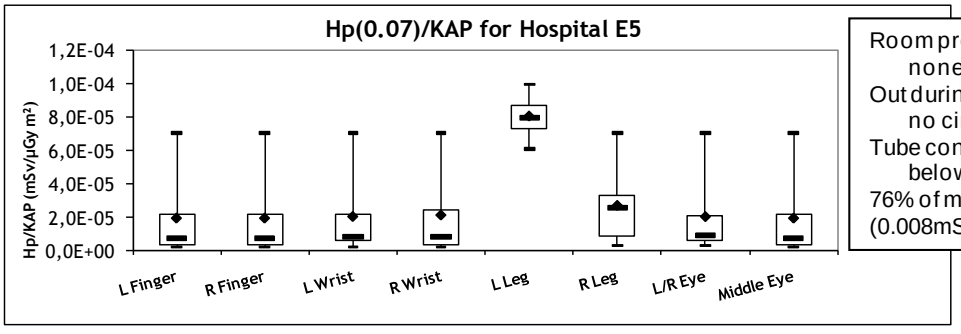
Room protective equipment:
RP cabin (6), RP cabin + ceiling (6)
Out during cine:
no
Tube configuration:
biplane
52% of measurements are LDL (0.008mSv)



Room protective equipment:
RP cabin (6), RP cabin + ceiling (6)
Out during cine:
no cine
Tube configuration:
below
25% of measurements are LDL (0.008mSv)
The high dose/KAP corresponds to a case with small KAP and high dose



Room protective equipment:
Table (3), table + ceiling (5), ceiling (1), table + patient (1)
Out during cine:
no cine
Tube configuration:
below (5), biplane (5)
18% of measurements are LDL (0.008mSv)
5 cases of max doses out of the 8 identified belong to this hospital



Room protective equipment:
none
Out during cine:
no cine
Tube configuration:
below
76% of measurements are LDL (0.008mSv)

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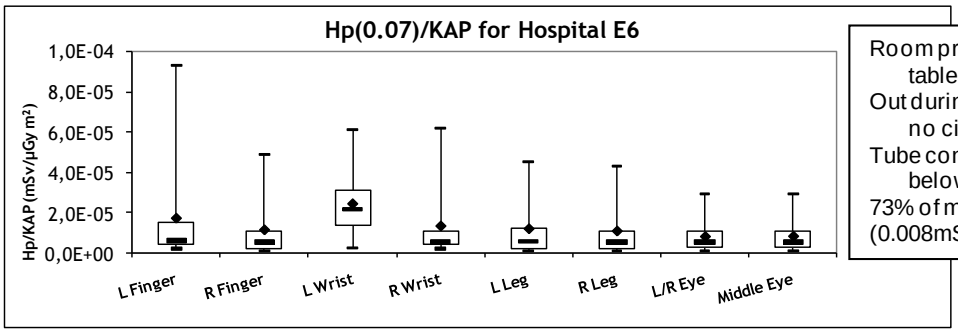
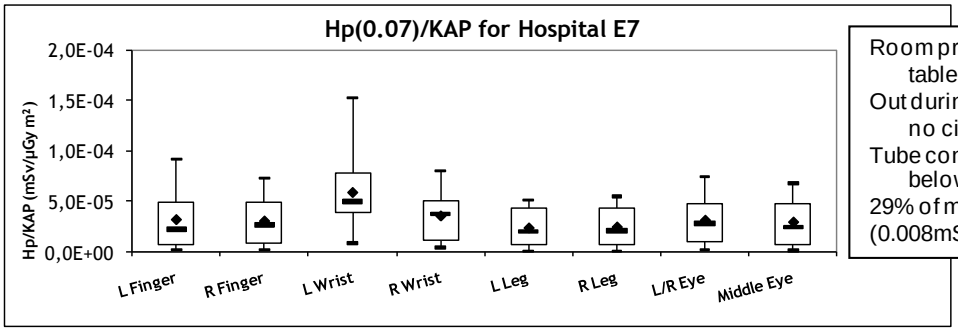
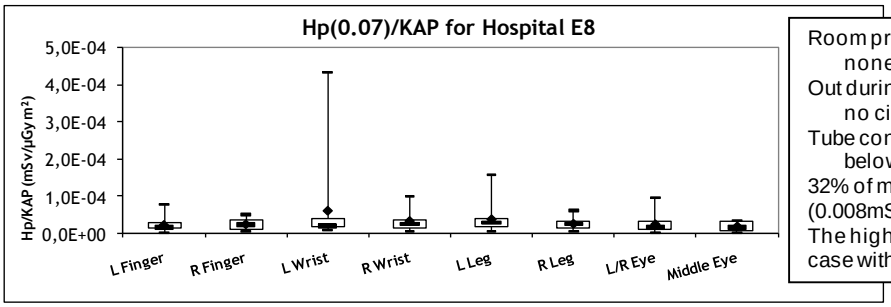


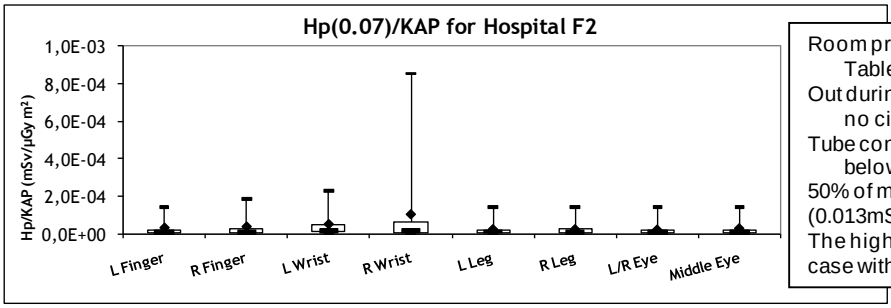
Room protective equipment:
table + ceiling
Out during cine:
no cine
Tube configuration:
below
73% of measurements are LDL (0.008mSv)



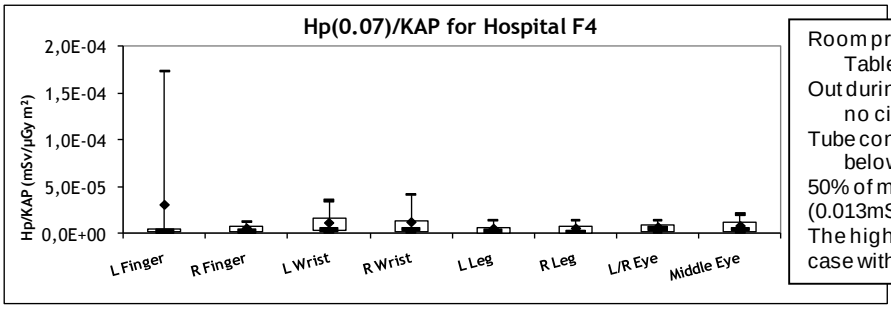
Room protective equipment:
table + ceiling
Out during cine:
no cine
Tube configuration:
below
29% of measurements are LDL (0.008mSv)



Room protective equipment:
none (12), ceiling (1)
Out during cine:
no cine
Tube configuration:
below
32% of measurements are LDL (0.008mSv)
The high dose/KAP corresponds to a case with small KAP and high dose



Room protective equipment:
Table + ceiling
Out during cine:
no cine
Tube configuration:
below
50% of measurements are LDL (0.013mSv)
The high dose/KAP corresponds to a case with small KAP and high dose



Room protective equipment:
Table + ceiling
Out during cine:
no cine
Tube configuration:
below
50% of measurements are LDL (0.013mSv)
The high dose/KAP corresponds to a case with small KAP and high dose

Appendix 2: Extrapolation to annual doses (tables and graphs)

Table 12: Table with the estimation of the annual doses for the fingers, wrist, legs and eyes for the ERCP procedures. The last columns indicate the percentage of the respective annual limit.

Operator	Procedure	# Procedures	# Measmts	Max <Dose> per proc (mSv)				Annual Dose (mSv)				Percentage of Annual limit			
				Finger	*Wrist*	*Leg*	*Eye*	*Finger*	*Wrist*	*Leg*	*Eye*	*Finger*	*Wrist*	*Leg*	*Eye*
B3	ERCP	**100**	7	**0,68**	0,42	**0,01**	0,50	**68,07**	42,33	**1,07**	50,36	**0,14**	8,47%	**0,21%**	33,57%
F8	ERCP	**107**	4	**0,03**	0,02	**0,04**	0,04	**2,97**	2,54	**4,42**	3,85	**0,01**	0,51%	**0,88%**	2,57%
D5	ERCP	**30**	7	**0,01**	0,02	**0,06**	0,01	**0,39**	0,48	**1,68**	0,26	**0,00**	0,10%	**0,34%**	0,17%
E11	ERCP	**70**	4	**0,01**	0,04	**0,02**	0,01	**0,89**	2,73	**1,30**	0,56	**0,00**	0,55%	**0,26%**	0,37%
OP1	ERCP	**110**	5	**0,02**	0,03	**0,02**	0,02	**1,98**	3,53	**2,12**	1,98	**0,00**	0,71%	**0,42%**	1,32%
IRSN36	ERCP	**100**	5	**0,06**	0,05	**0,17**	0,03	**0,28**	0,23	**0,87**	0,15	**0,00**	0,05%	**0,17%**	0,10%
IRSN41	ERCP	**300**	10	**0,08**	0,03	**0,09**	0,04	**0,78**	0,31	**0,88**	0,40	**0,00**	0,06%	**0,18%**	0,27%

APPENDIX 2

Table 2: Table with the estimation of the annual doses for the fingers, wrist, legs and eyes for the interventional cardiology procedures. The last columns indicate the percentage of the respective annual limit.

Operator	Procedure	# Procedures	# Measmts	Max <Dose> per proc (mSv)				Annual Dose (mSv)				Percentage of Annual limit			
				Finger	*Wrist*	*Leg*	*Eye*	*Finger*	*Wrist*	*Leg*	*Eye*	*Finger*	*Wrist*	*Leg*	*Eye*
B11	CA&PTCA	255	4	0,16	0,16	0,32	0,04	41,90	40,82	81,15	9,50	8,38%	8,16%	16,23%	6,33%
B16	PM & ICD	151	4	3,39	1,75	2,28	0,50	512,06	263,81	344,78	75,59	102,41%	52,76%	68,96%	50,39%
	RF ablations	61	1	0,75	0,26	0,04	0,88	45,49	15,88	2,63	53,65	9,10%	3,18%	0,53%	35,77%
B17	CA&PTCA	233	5	0,31	0,41	0,28	0,12	71,43	94,62	66,04	27,55	14,29%	18,92%	13,21%	18,37%
F12	RF ablations	183	10	0,02	0,05	0,01	0,01	3,47	9,19	1,82	1,71	0,69%	1,84%	0,36%	1,14%
F13	PM&ICD	44	7	0,56	0,39	0,76	0,03	24,86	17,34	33,32	1,12	4,97%	3,47%	6,66%	0,75%
A15	CA&PTCA	750	4	0,07	0,15	0,07	0,05	56,22	112,02	56,07	39,94	11,24%	22,40%	11,21%	26,62%
E3	CA&PTCA	1157	4	0,08	0,09	0,22	0,06	94,68	102,13	255,57	68,72	18,94%	20,43%	51,11%	45,82%
E10	CA&PTCA	998	4	0,02	0,04	0,12	0,05	16,22	42,40	120,70	46,06	3,24%	8,48%	24,14%	30,71%
I1	CA&PTCA		13	0,21	0,14	0,02	0,02	0,00	0,00	0,00	0,00	0,00%	0,00%	0,00%	0,00%
G2	CA&PTCA	714	4	0,04	0,05	0,05	0,01	29,94	33,71	39,23	10,21	5,99%	6,74%	7,85%	6,81%
G4	CA&PTCA	904	3	0,05	0,05	0,03	0,03	41,89	49,72	22,83	25,83	8,38%	9,94%	4,57%	17,22%
G5	RF ablation	189	4	0,06	0,10	0,05	0,07	11,83	19,11	8,60	13,17	2,37%	3,82%	1,72%	8,78%
	PM&ICD	185	4	0,60	0,53	0,32	0,13	111,04	97,77	58,93	24,35	22,21%	19,55%	11,79%	16,23%
G6	RF ablation	187	6	0,02	0,08	0,01	0,04	4,49	14,84	2,06	7,28	0,90%	2,97%	0,41%	4,85%
	PM&ICD	88	3	1,57	0,98	0,39	0,28	137,74	86,68	34,70	25,07	27,55%	17,34%	6,94%	16,71%
OP2	CA PTCA	605	6	0,03	0,02	0,03	0,02	19,36	10,89	17,04	10,89	3,87%	2,18%	3,41%	7,26%
OP3	CA PTCA	630	5	0,02	0,03	0,06	0,02	11,34	16,79	38,10	11,34	2,27%	3,36%	7,62%	7,56%
OP10	RF ablation	58	10	0,02	0,03	0,06	0,02	1,04	1,53	3,32	1,05	0,21%	0,31%	0,66%	0,70%
OP12	PM/ICD		7	0,20		0,27	0,04					0,00%	0,00%	0,00%	0,00%
OP15	PM/ICD	400	6	0,53		0,25	0,08	213,20		100,38	31,43	42,64%	0,00%	20,08%	20,96%
OP22	RF ablation	100	10		0,09	0,16	0,02		8,59	15,90	1,80	0,00%	1,72%	3,18%	1,20%
OP40	CA PTCA	630	9	0,02	0,03	0,06	0,02	11,34	21,91	39,27	12,49	2,27%	4,38%	7,85%	8,33%
MK	CA PTCA	500	4	0,05	0,04	0,01	0,01	24,00	19,00	4,50	5,00	4,80%	3,80%	0,90%	3,33%
TJ	CA PTCA	1000	4	0,11	0,11	0,01	0,03	114,00	107,00	14,00	27,00	22,80%	21,40%	2,80%	18,00%
	PM/ICD	24	7	0,33	0,15	0,12	0,03	7,90	3,70	2,83	0,65	1,58%	0,74%	0,57%	0,43%
AB	PM/ICD	104	4	0,21	0,10	0,01	0,06	21,84	10,30	0,94	6,14	4,37%	2,06%	0,19%	4,09%
	PM/ICD							29,74	13,99	3,77	6,78	5,95%	2,80%	0,75%	4,52%

Table 2 (cont.)

Operator	Procedure	# Procedures	# Measmts	Max <Dose> per proc (mSv)				Annual Dose (mSv)				Percentage of Annual limit			
				Finger	*Wrist*	*Leg*	*Eye*	*Finger*	*Wrist*	*Leg*	*Eye*	*Finger*	*Wrist*	*Leg*	*Eye*
TR	PM/ICD	**100**	5	**0,09**	0,06	**0,02**	0,02	**8,70**	5,80	**1,90**	1,60	**1,74%**	1,16%	**0,38%**	1,07%
BB	RF ablation	**70**	10	**0,06**	0,06	**0,04**	0,01	**4,27**	3,92	**2,59**	0,56	**0,85%**	0,78%	**0,52%**	0,37%
JR	RF ablation	**100**	5	**0,07**	0,11	**0,18**	0,06	**7,40**	10,60	**18,10**	6,30	**1,48%**	2,12%	**3,62%**	4,20%
IRSN11	PM/ICD	**110**	4	**0,02**	0,03	**0,07**	0,01	**0,07**	0,11	**0,29**	0,03	**0,01%**	0,02%	**0,06%**	0,02%
IRSN19	RF ablation	**65**	5	**0,01**	0,03	**0,22**	0,04	**0,06**	0,15	**1,10**	0,19	**0,01%**	0,03%	**0,22%**	0,13%
IRSN19	PM/ICD	**100**	4	**0,16**	0,18	**0,30**	0,06	**0,63**	0,73	**1,20**	0,24	**0,13%**	0,15%	**0,24%**	0,16%
IRSN24	RF ablation	**47**	9	**0,07**	0,36	**0,86**	0,17	**0,62**	3,22	**7,73**	1,51	**0,12%**	0,64%	**1,55%**	1,01%
IRSN24	PM/ICD	**113**	5	**0,84**	0,55	**0,72**	0,16	**4,19**	2,77	**3,60**	0,80	**0,84%**	0,55%	**0,72%**	0,53%
SMU1	CA PTCA	**500**	5	**0,34**	0,26	**0,07**	0,04	**198,20**	187,10	**38,40**	29,90	**39,60%**	37,40%	**7,70%**	19,90%

APPENDIX 2

Table 3: Table with the estimation of the annual doses for the fingers, wrist, legs and eyes for the interventional radiology procedures. The last columns indicate the percentage of the respective annual limit.

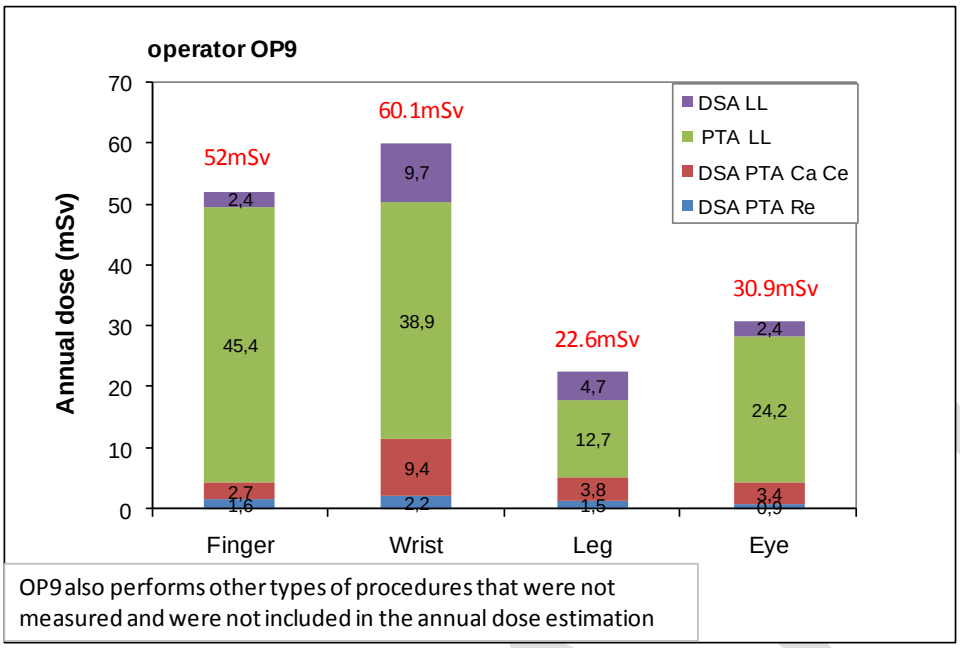
Operator	Procedure	# Procedures	# Measmts	Max <Dose> per proc (mSv)				Annual Dose (mSv)				Percentage of Annual limit		
				Finger	*Wrist*	*Leg*	*Eye*	*Finger*	*Wrist*	*Leg*	*Eye*	*Finger*	*Wrist*	*Leg*
B1	emb. Vena sperm	30	10	0,65	0,48	0,01	0,40	19,46	14,38	0,30	12,10	3,89%	2,88%	0,06%
	chemo emb.	5	5	1,05	1,63	2,54	0,81	5,25	8,16	12,70	4,06	1,05%	1,63%	2,54%
	renal/abd/pelvis	25	2	0,69	0,52	0,91	0,29	17,25	12,97	22,84	7,15	3,45%	2,59%	4,57%
	neuro emb.	8												
	embolisatie IntraCran	15												
	diagn procedures													
A17	Neuro emb	77	8	0,02	0,03	0,12	0,03	1,80	2,16	9,29	2,50	0,36%	0,43%	1,86%
	renal/abd	286	4	0,45	0,20	0,33	0,05	129,33	58,42	95,10	14,33	25,87%	11,68%	19,02%
	cerebral	22	8	0,02	0,03	0,12	0,03	0,51	0,62	2,65	0,71	0,10%	0,12%	0,53%
	lower limbs	165	5	0,09	0,05	0,10	0,03	14,94	7,56	17,03	4,14	2,99%	1,51%	3,41%
A6	Neuro	88	8	0,04	0,05	0,04	0,05	3,94	4,16	3,48	4,66	0,79%	0,83%	0,70%
	cerebral	22	8	0,04	0,05	0,04	0,05	0,98	1,04	0,87	1,16	0,20%	0,21%	0,17%
	renal/abd	143	1	0,18	0,18	2,34	0,02	26,12	25,54	334,88	3,52	5,22%	5,11%	66,98%
	lower limbs	11	4	0,09	0,05	0,10	0,03	1,00	0,50	1,14	0,28	0,20%	0,10%	0,23%
A10	cerebral	11		0,03	0,04	0,08	0,04	0,37	0,41	0,88	0,47	0,07%	0,08%	0,18%
	renal/abd	231		0,32	0,19	1,34	0,04	73,32	44,22	308,88	8,63	14,66%	8,84%	61,78%
	lower limbs	88		0,09	0,05	0,10	0,03	7,97	4,03	9,08	2,21	1,59%	0,81%	1,82%
E15	vertebroplasty	95	9	4,35	1,84	0,19	0,49	413,14	175,14	17,82	46,14	82,63%	35,03%	3,56%
	discografie	54						234,84	99,55	10,13	26,22	46,97%	19,91%	2,03%
	lower limbs	43	6	0,01	0,01	0,01	0,01	0,64	0,42	0,34	0,34	0,13%	0,08%	0,07%
E1	emb. vena spermatica	30	11	0,21	0,13	0,01	0,08	6,37	3,87	0,24	2,41	1,27%	0,77%	0,05%
	neuro embolisaties	79	10	0,02	0,03	0,05	0,04	1,79	2,54	4,08	3,30	0,36%	0,51%	0,82%
	DSA cerebral	219	7	0,06	0,05	0,01	0,02	13,64	9,89	1,75	4,01	2,73%	1,98%	0,35%
K1	vertebro/kypho	176	8	2,92	1,45	0,08	0,36	513,60	255,93	13,86	63,62	102,72%	51,19%	2,77%
	DSA PTA LL	167	4	0,05	0,03	0,08	0,02	31,76	26,67	7,00	3,27	6,35%	5,33%	1,40%
OP6	DSA PTA Ca Ce		2	0,07	0,04	0,02	0,02							
	Embolisation		2	0,05	0,02	0,02	0,02		105,00	52,00	0,50		20,98%	10,28%
	DSA PTA Re		2	0,73	0,69	0,02	0,03							
OP7	DSA PTA Ca Ce	250	5	0,02	0,06	0,02	0,03	4,86	14,15	5,95	8,68	0,97%	2,83%	1,19%
	Embolisation	80	5	0,02	0,05	0,06	0,03	1,52	3,60	5,06	2,69	0,30%	0,72%	1,01%
	DSA PTA Re	34	1	0,05	0,06	0,04	0,03	1,59	2,17	1,46	0,92	0,32%	0,43%	0,29%
OP9	DSA PTA Ca Ce	130,5	1	0,02	0,07	0,03	0,03	2,71	9,36	3,81	3,39	0,54%	1,87%	0,76%
	PTA LL	61,5	2	0,74	0,63	0,21	0,39	45,37	38,89	12,73	24,20	9,07%	7,78%	2,55%
	DSA LL	131	1	0,02	0,07	0,04	0,02	2,36	9,72	4,65	2,36	0,47%	1,94%	0,93%
	total	357						52,03	60,14	22,65	30,86	10,41%	12,03%	4,53%
OP24	PTA LL	50	4		0,28	0,04	0,08		14,06	2,10	3,78		2,81%	0,42%
	DSA LL	206	11		0,04	0,03	0,02		9,03	6,70	3,71		1,81%	1,34%
	Embolisation	30	8		0,08	0,05	0,06		2,49	1,64	1,75		0,50%	0,33%
	DSA PTA Ca Ce	112	5		0,03	0,02	0,02		3,33	2,31	2,02		0,67%	0,46%
	DSA PTA Re	56	6		0,07	0,09	0,05		4,14	4,79	2,83		0,83%	0,96%
	total	454							33,04	17,54	14,08		6,61%	3,51%

Table 3 (cont.)

Operator	Procedure	# Procedures	# Measmts	Max <Dose> per proc (mSv)				Annual Dose (mSv)				Percentage of Annual limit		
				Finger	*Wrist*	*Leg*	*Eye*	*Finger*	*Wrist*	*Leg*	*Eye*	*Finger*	*Wrist*	*Leg*
OP33	PTA LL DSA LL Embolisation DSA PTA Ca Ce DSA PTA Re	454	5	0,02	0,03	0,16	0,03	8,17	13,41	73,74	13,78	1,63%	2,68%	14,75%
OP34	DSA PTA Ca Ce	130,5	7	0,04	0,06	0,06	0,04	5,41	7,74	7,52	5,68	1,08%	1,55%	1,50%
	PTA LL	61,5	2	0,88	0,63	0,40	0,20	53,93	38,97	24,89	12,16	10,79%	7,79%	4,98%
	DSA LL	131	3	0,02	0,03	0,02	0,02	2,36	3,44	2,95	2,36	0,47%	0,69%	0,59%
	total	323						61,70	50,15	35,36	20,20	12,34%	10,03%	7,07%
OP35	DSA PTA Ca Ce	50	10	0,09	0,14	0,03	0,14	4,26	6,76	1,60	7,00	0,85%	1,35%	0,32%
	PTA LL	34	3	0,60	0,66	0,29	0,36	20,37	22,32	9,95	12,15	4,07%	4,46%	1,99%
	DSA LL	70	7	0,38	0,24	0,05	0,04	26,91	16,77	3,17	3,04	5,38%	3,35%	0,63%
	Embolisation (Liver chemo)	20	5	0,54	1,29	0,20	0,61	10,88	25,79	4,10	12,25	2,18%	5,16%	0,82%
	DSA PTA Re	38	1	0,16	0,06	0,07	0,02	6,12	2,29	2,72	0,79	1,22%	0,46%	0,54%
	total	212						68,54	73,94	21,54	35,23	13,71%	14,79%	4,31%
OP41	Embolisation (Aneurysm+AVM)	90	8		0,62	0,25	0,95		56,13	22,73	85,26	0,00%	11,23%	4,55%
ZK	Embolisation	44	9	0,47	1,17	0,09	0,06	20,72	51,48	3,87	2,68	4,14%	10,30%	0,77%
	DSA PTA Carotid&Cerebral	50	5	0,03	0,03	0,01	0,02	1,60	1,40	0,35	0,90	0,32%	0,28%	0,07%
	DSA PTA LL	98	5	0,18	0,21	0,01	0,05	17,84	20,68	1,08	4,90	3,57%	4,14%	0,22%
	DSA PTA R	9	1	0,02	0,03	0,01	0,01	0,16	0,26	0,05	0,13	0,03%	0,05%	0,01%
	total							40,32	73,82	5,35	8,61	8,06%	14,76%	1,07%
IRSN38	DSA PTA LL	400	4	0,29	0,10	0,17	0,05	1,16	0,41	0,67	0,19	0,23%	0,08%	0,13%
IRSN38	DSA PTA R	100	5	0,16	0,14	0,39	0,03	0,80	0,68	1,96	0,16	0,16%	0,14%	0,39%
IRSN39	DSA PTA LL	400	12	0,06	0,05	0,15	0,05	0,71	0,62	1,76	0,54	0,14%	0,12%	0,35%
IRSN39	DSA PTA R	100	10	0,10	0,06	0,13	0,08	1,00	0,63	1,29	0,82	0,20%	0,13%	0,26%
SMU2	DSA PTA LL	500	5	0,08	0,08	0,10	0,01	88,60	73,00	221,00	13,70	0,20%	0,10%	0,40%
SMU2	Embolization	50	5	0,86	0,61	0,59	0,12	43,00	30,00	30,00	6,10	8,60%	6,10%	5,90%

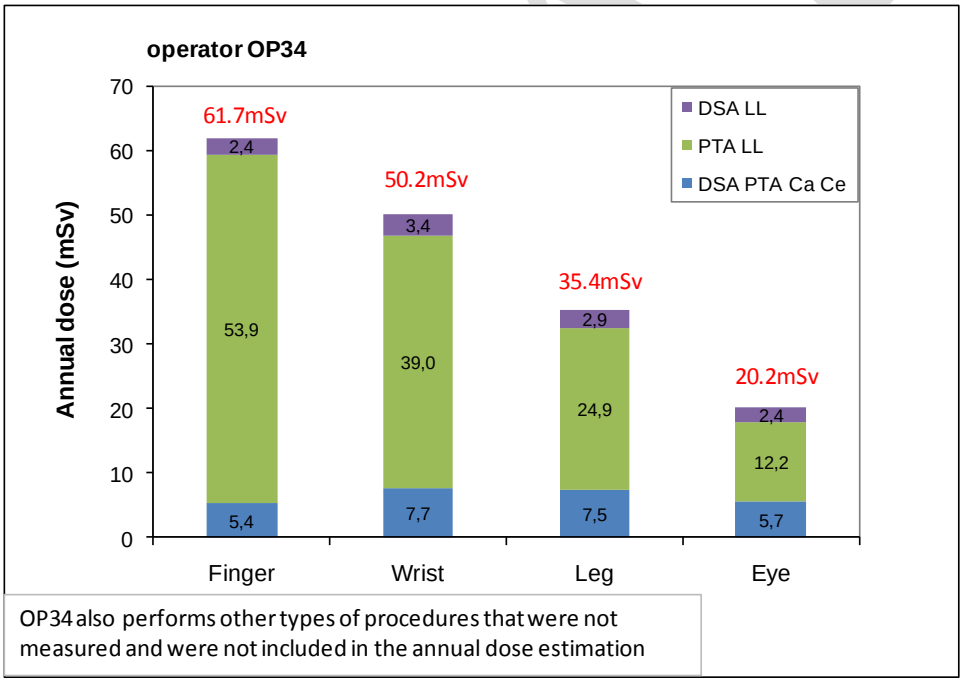
APPENDIX 2

1. Graphs representing the annual doses for interventional radiology procedures



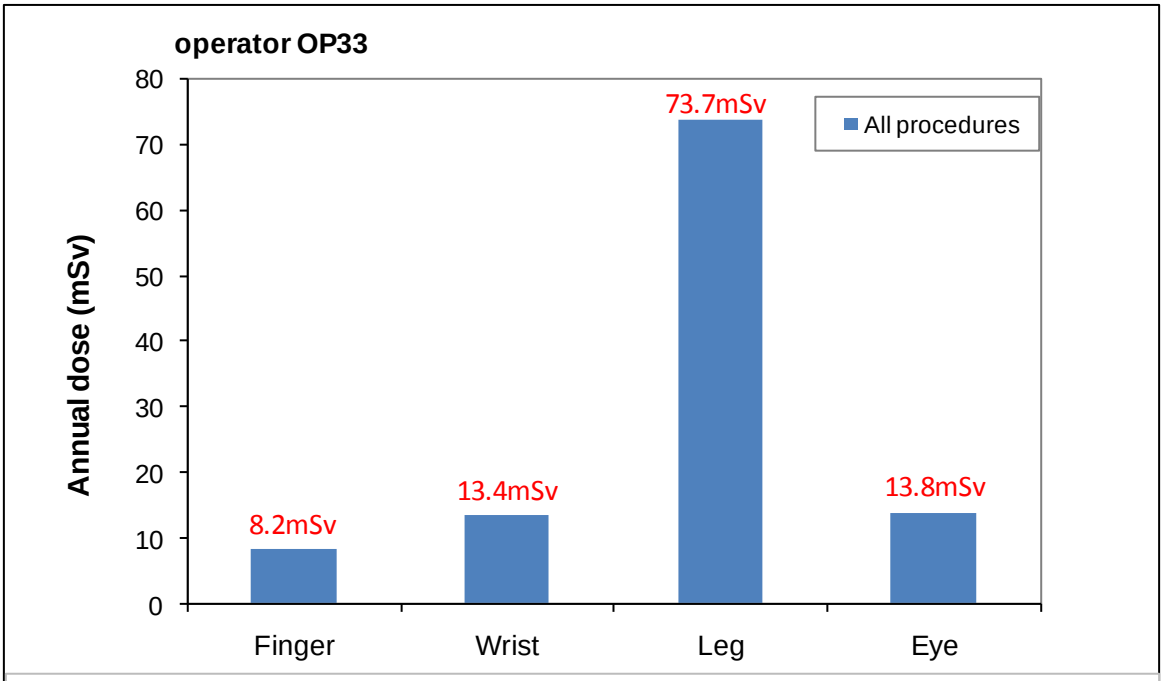
OP9 also performs other types of procedures that were not measured and were not included in the annual dose estimation

62 PTA LL
131 DSA LL
131 DSA PTA Ca Ce
34 DSA PTA Re
357 TOTAL

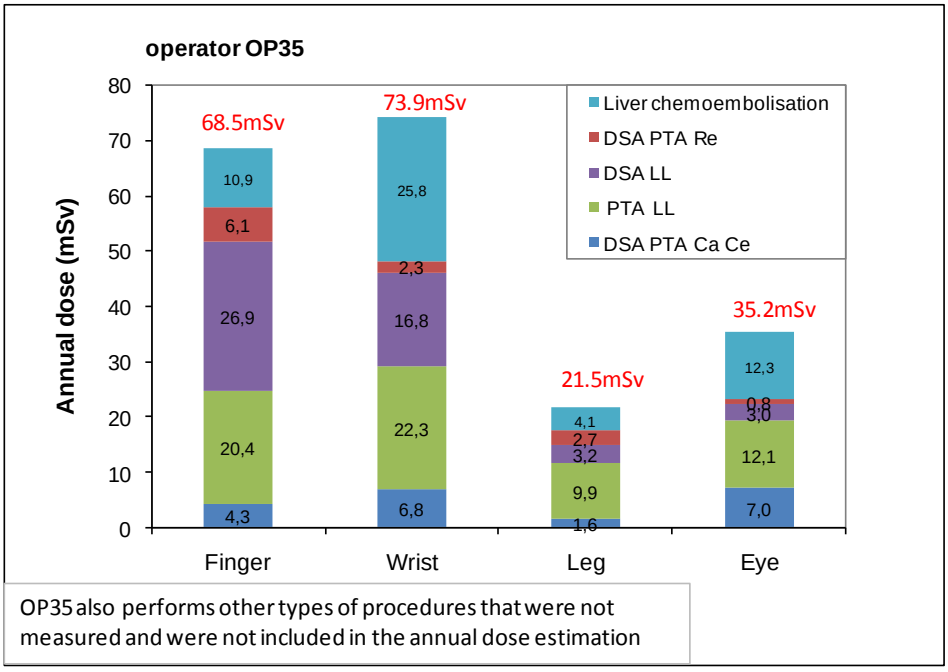


OP34 also performs other types of procedures that were not measured and were not included in the annual dose estimation

62 PTA LL
131 DSA LL
131 DSA PTA Ca Ce
323 TOTAL

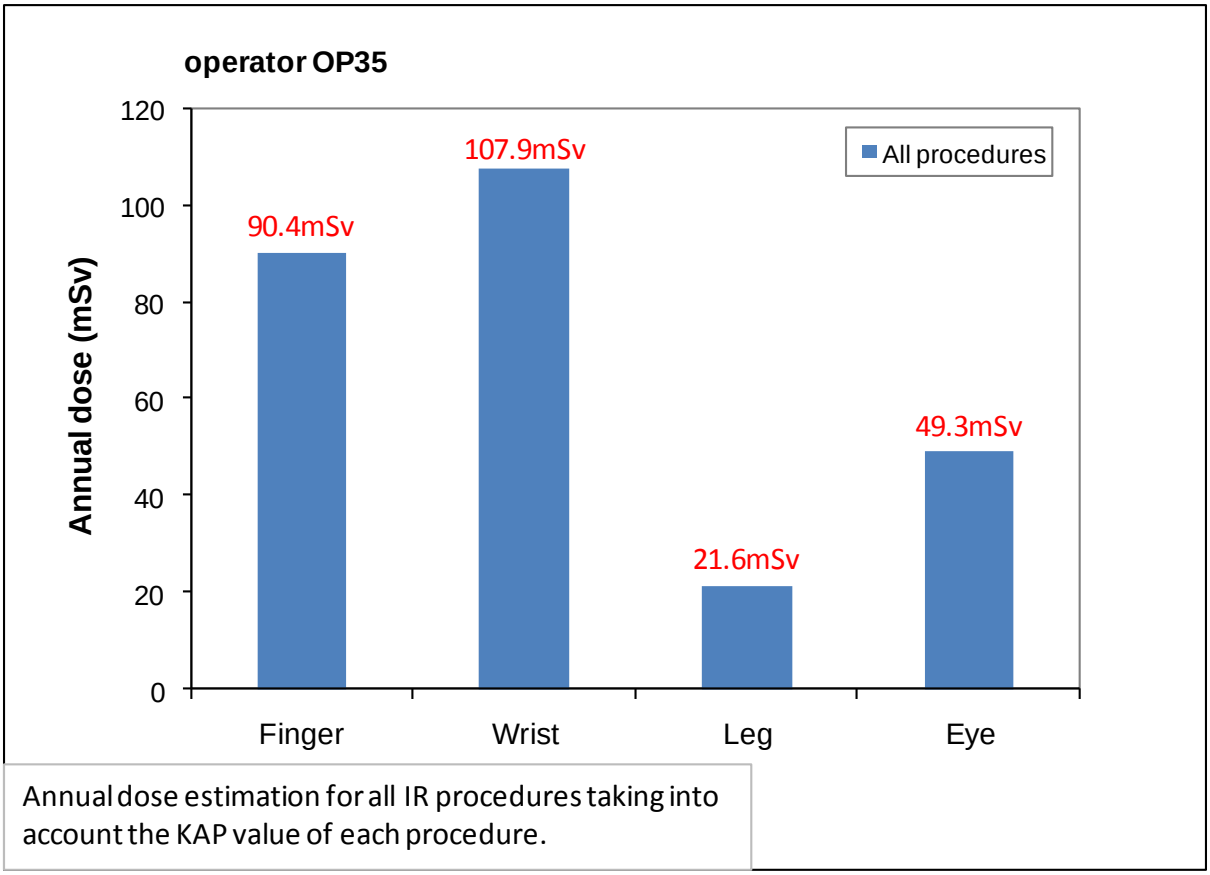


OP33 was mostly assisting OP24. Lower doses to the hands and wrists are recorded, however for the legs, the doses are higher because where he was standing as assistant he was not always protected by the table shield.

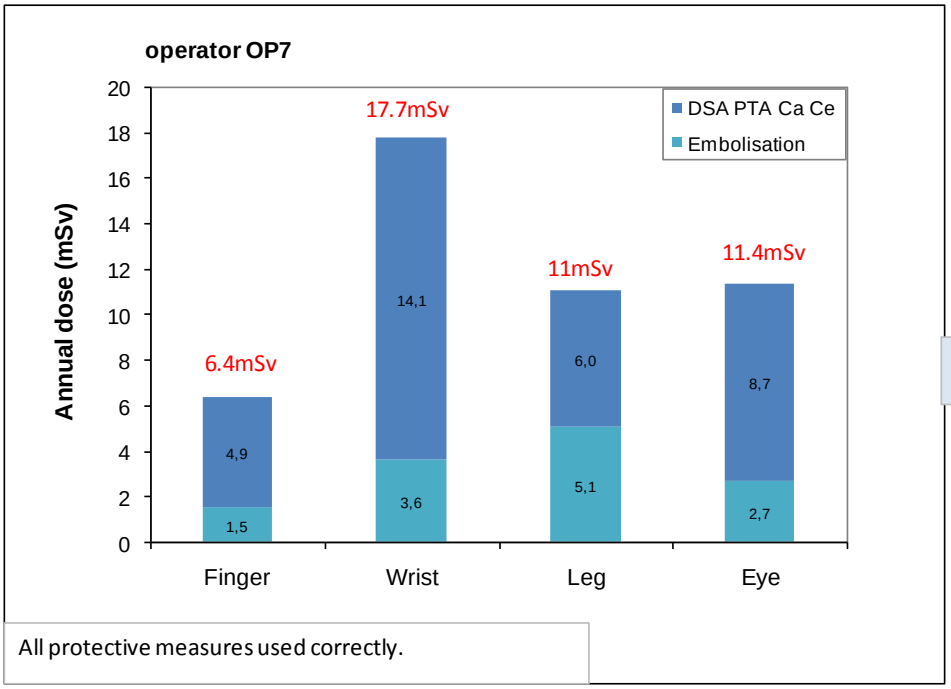


OP35 also performs other types of procedures that were not measured and were not included in the annual dose estimation

34 PTA LL
70 DSA LL
20 Liver Chemoembolisations
50 DSA PTA Ca Ce
38 DSA PTA Re
212 TOTAL

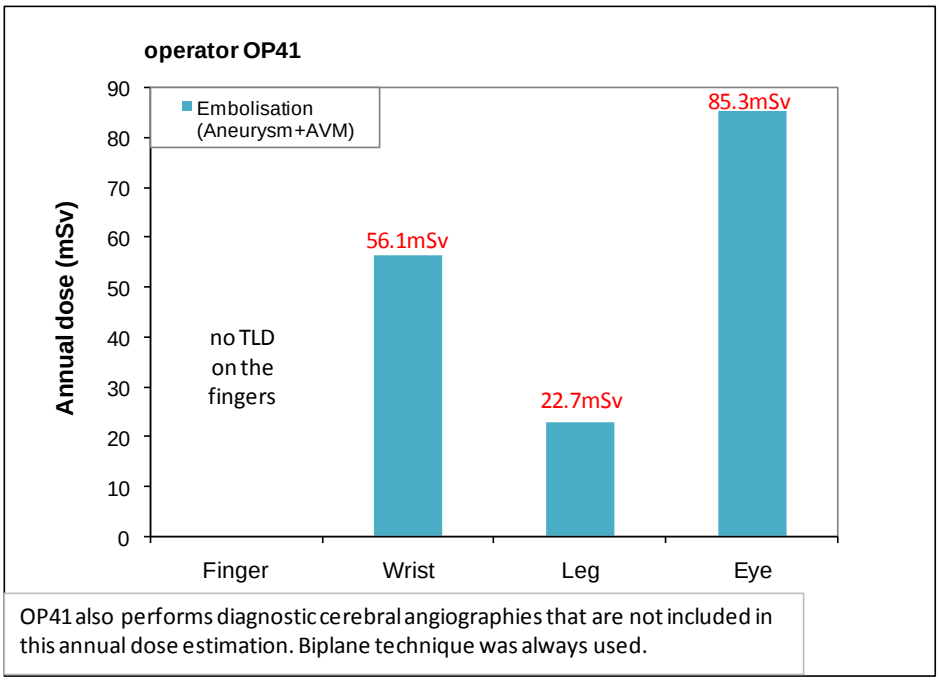


Annual dose estimation for all IR procedures taking into account the KAP value of each procedure.



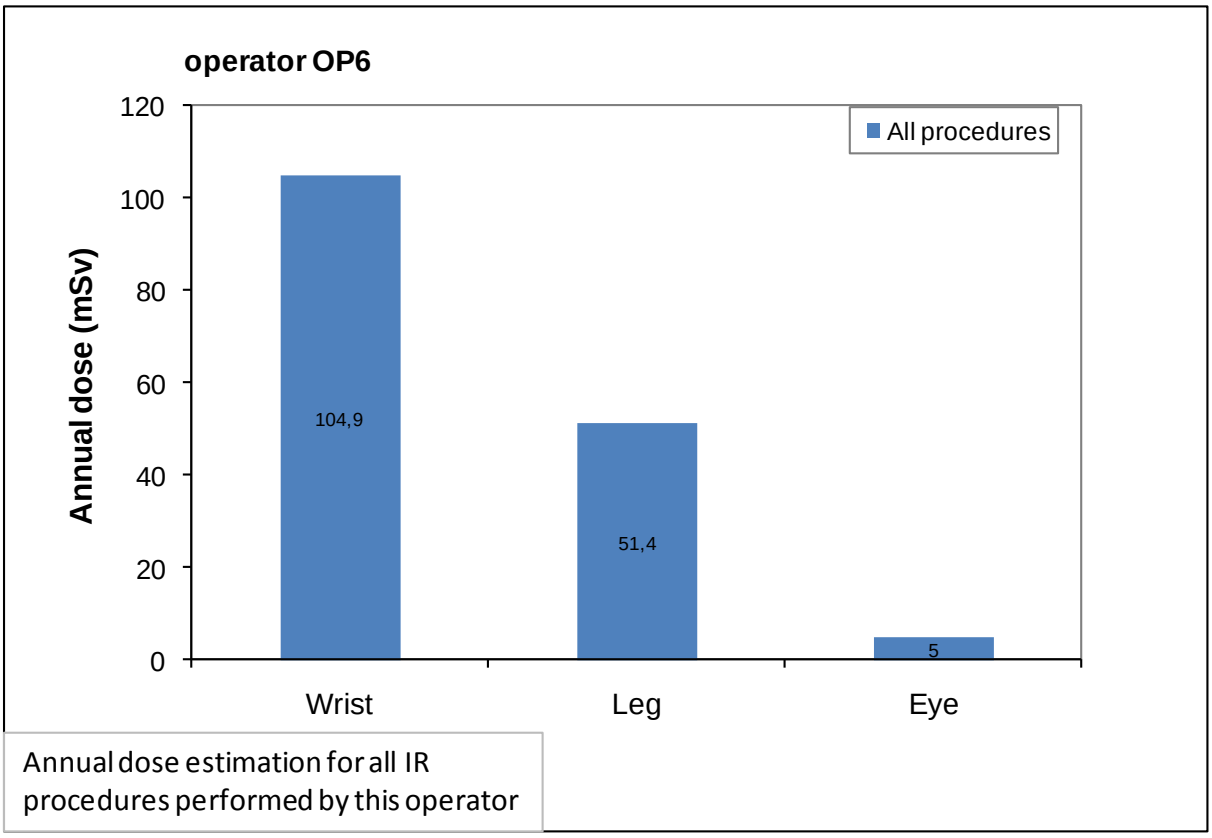
All protective measures used correctly.

80 Neuroembolisations
250 DSA Ca Ce



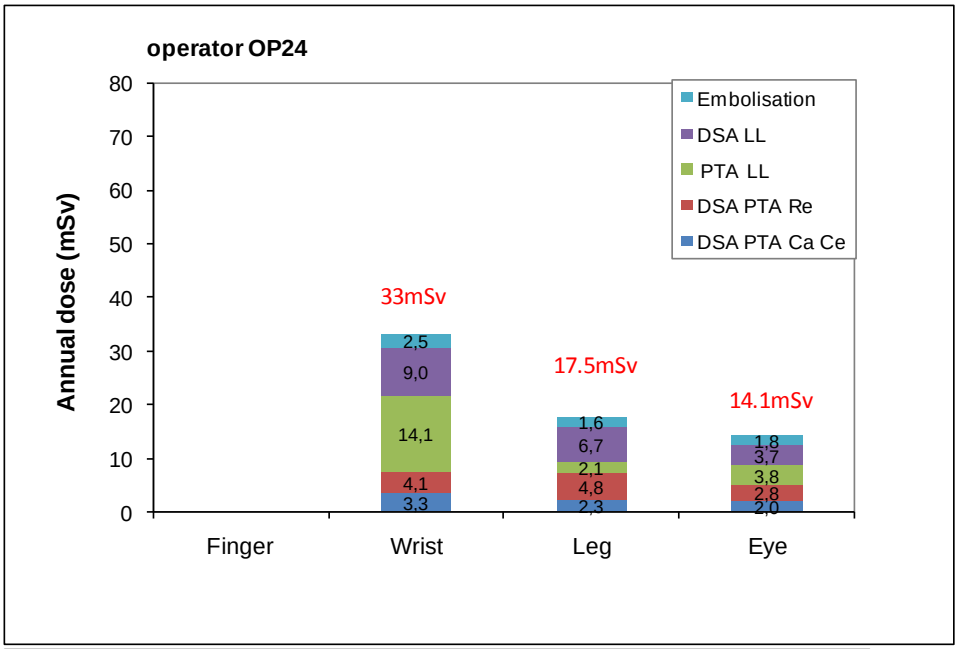
OP41 also performs diagnostic cerebral angiographies that are not included in this annual dose estimation. Biplane technique was always used.

90 Neuroembolisations

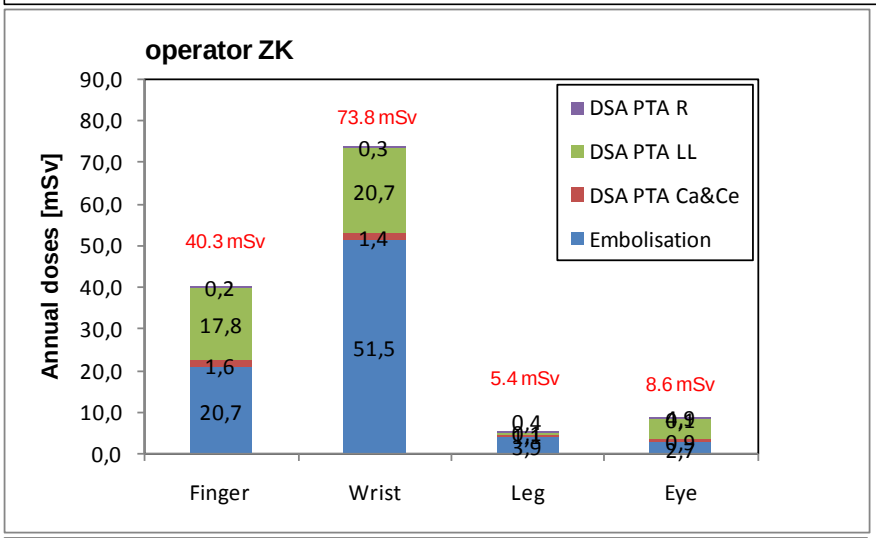


Annual dose estimation for all IR procedures performed by this operator

APPENDIX 2

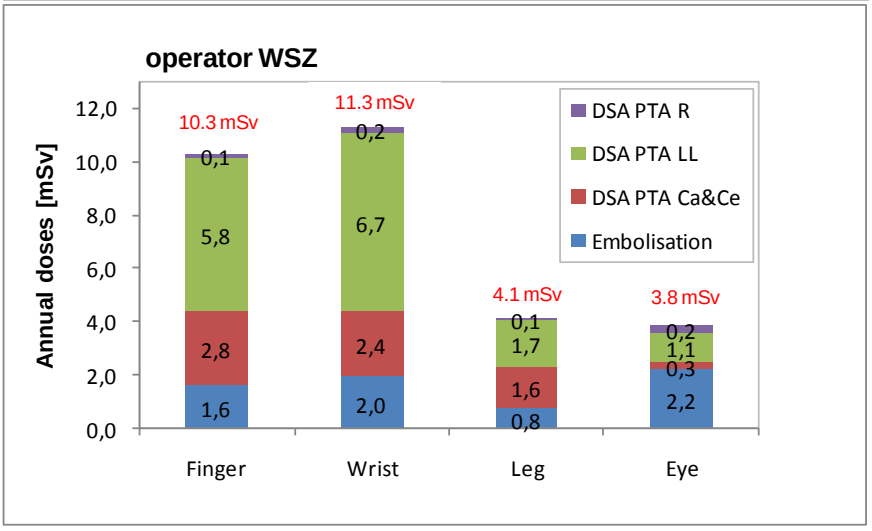


50 PTA LL
206 DSA LL
30 Embolisation
112 DSA PTA Ca Ce
56 DSA PTA Re
454 TOTAL



Protective equipment:
* table shield

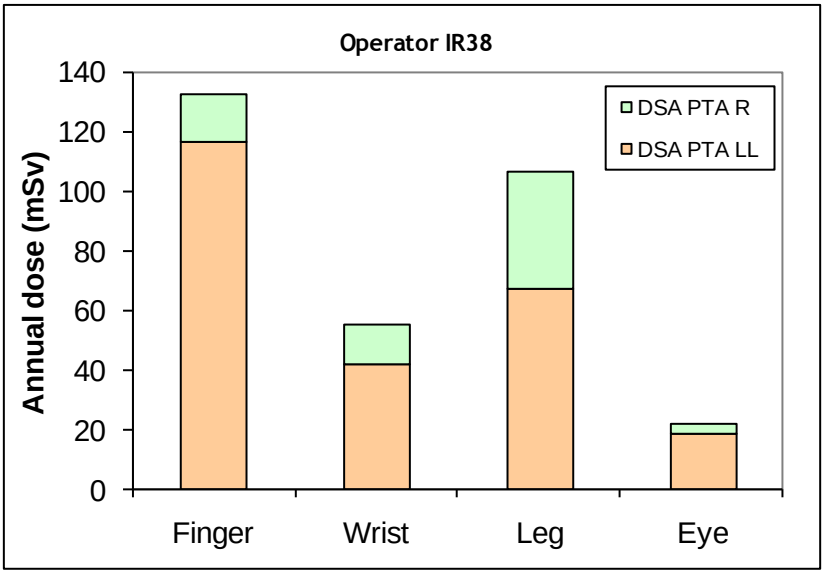
9 DSA PTA R /year
98 DSA PTA LL/year
50 DSA PTA Ca&Ce / year
44 Embolisations
TOTAL 201



Protective equipment:
* table shield

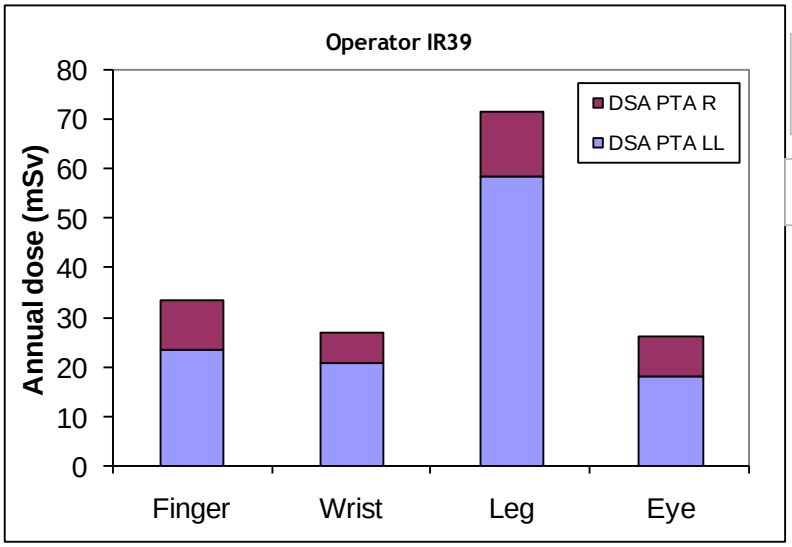
2 DSA PTA R /year
16 DSA PTA LL/year
17 DSA PTA Ca&Ce / year
16 Embolisations
TOTAL 51

APPENDIX 2



400 DSA/PTA LL
100 DSA/PTA R

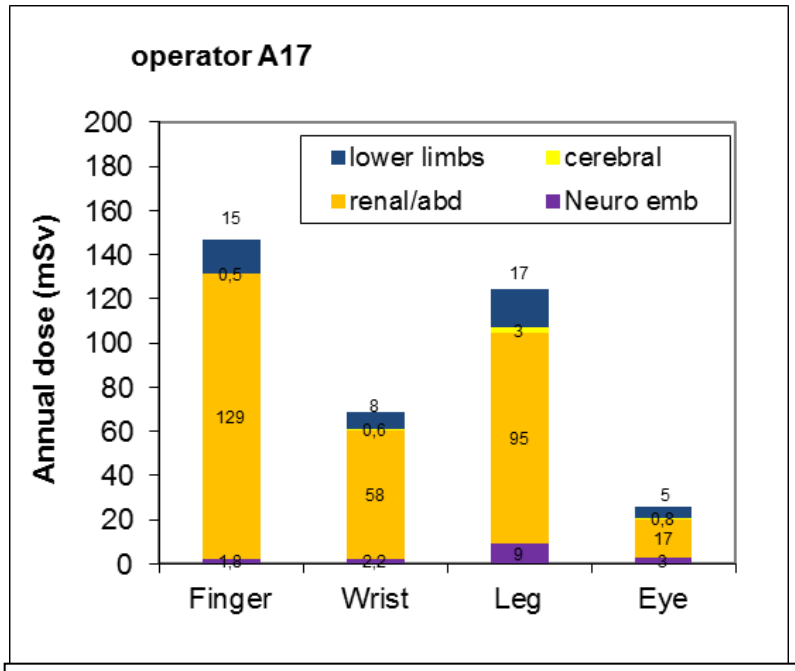
4 meas. For LL and 5 for



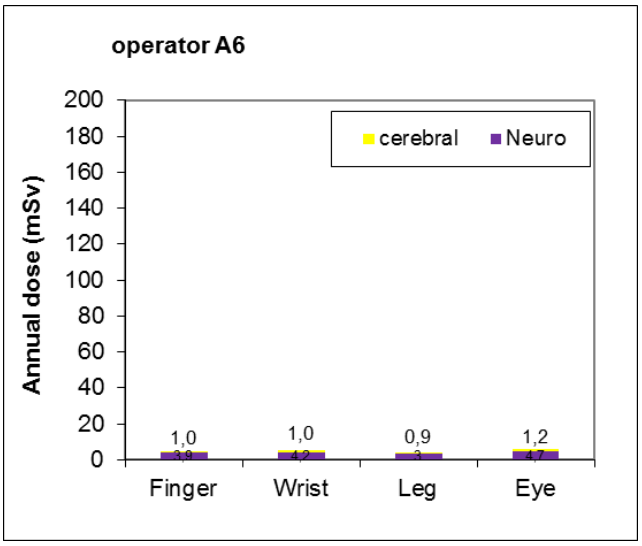
400 DSA/PTA LL
100 DSA/PTA R

12 mes. For LL and 10 for R

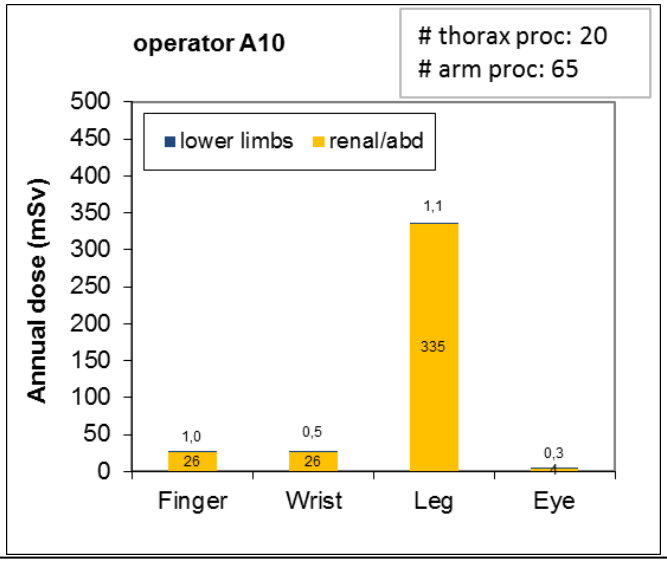
APPENDIX 2



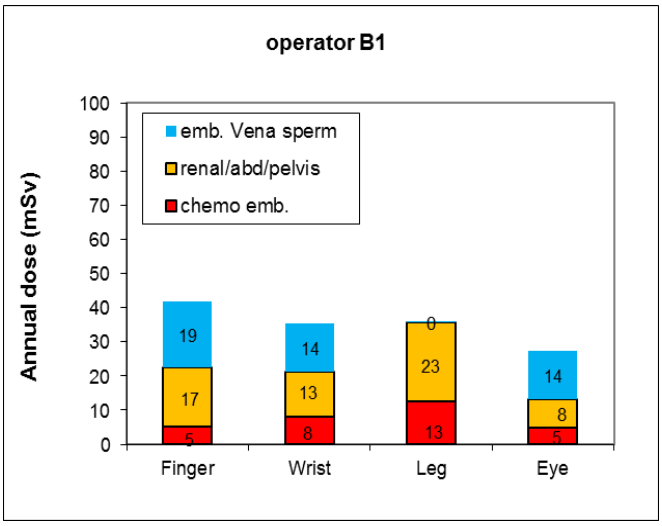
-	Procedure:	DSA/PTA Lower limbs	DSA/PTA renal/abdomen
-	Annual workload:	165	286
-	Tube configuration:	below	below
-	Room protection equipment:	table + ceiling	table + ceiling
-	Procedure:	DSA cerebral	neuro embolisations
-	Annual workload:	22	77
-	Tube configuration:	below	below
-	Room protection equipment:	table + ceiling	table + ceiling



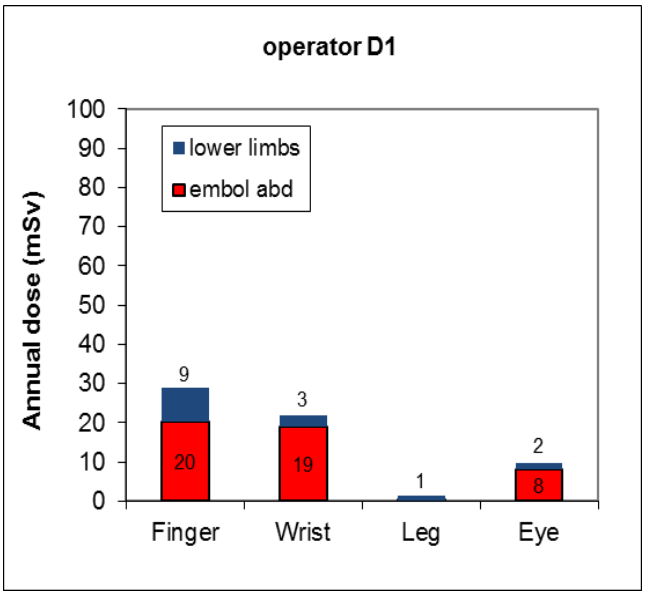
-	Procedure:	DSA cerebral	neuro embolisations
-	Annual workload:	22	88
-	Tube configuration:	below	below
-	Room protection equipment:	table + ceiling	table + ceiling



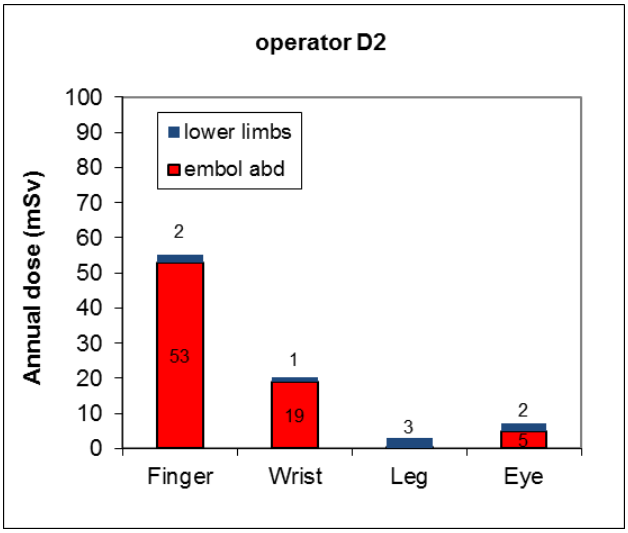
-	Procedure:	DSA/PTA Lower limbs	DSA/PTA renal/abdomen
-	Annual workload:	11	143
-	Tube configuration:	below	below
-	Room protection equipment:	table + ceiling	table + ceiling (left leg not protected by shield)



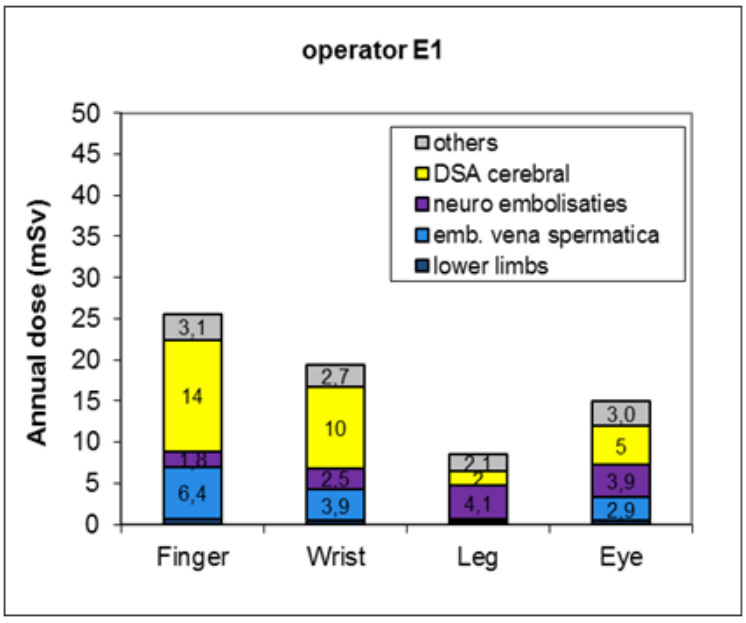
-	Procedure:	embolisatie vena spermatica	chemo embolisations
-	Annual workload:	30	5
-	Tube configuration:	above	below
-	Room protection equipment:	none	none
-	Procedure:	DSA/PTA Renal/abdomen	
-	Annual workload:	25	
-	Tube configuration:	below	
-	Room protection equipment:	none	



-	Procedure: abdomen	DSA lower limbs	embolisations
-	Annual workload:	150	15
-	Tube configuration:	above	above
-	Room protection equipment:	none	none
-	Out during cine acquisition:	yes	no

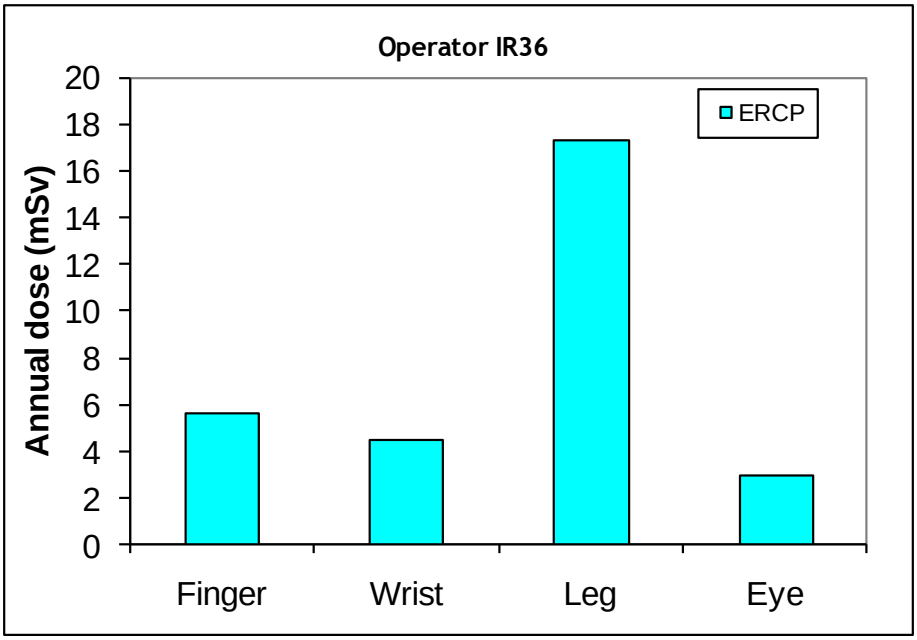


-	Procedure:	DSA lower limbs	embolisations abdomen
-	Annual workload:	150	15
-	Tube configuration:	above	above
-	Room protection equipment:	none	none
-	Out during cine acquisition:	yes	no



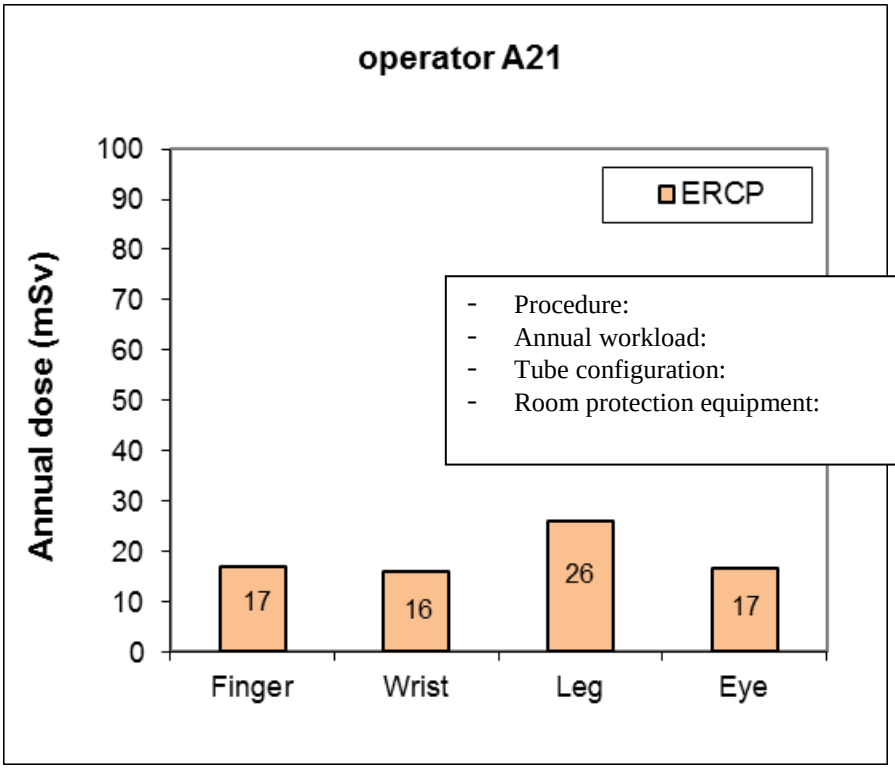
-	Procedure:	DSA/PTA Lower limbs	DSA cerebral
-	Annual workload:	43	219
-	Tube configuration:	below	below
-	Room protection equipment:	table	table
-	Out during cine acquisition:	yes	yes
-	Procedure:	neuro embolisations	embolisations vena spermatica
-	Annual workload:	79	30
-	Tube configuration:	below	above
-	Room protection equipment:	table + ceiling	none
-	Out during cine acquisition:	no	no

2. Graphs representing the annual doses for ERCP procedures

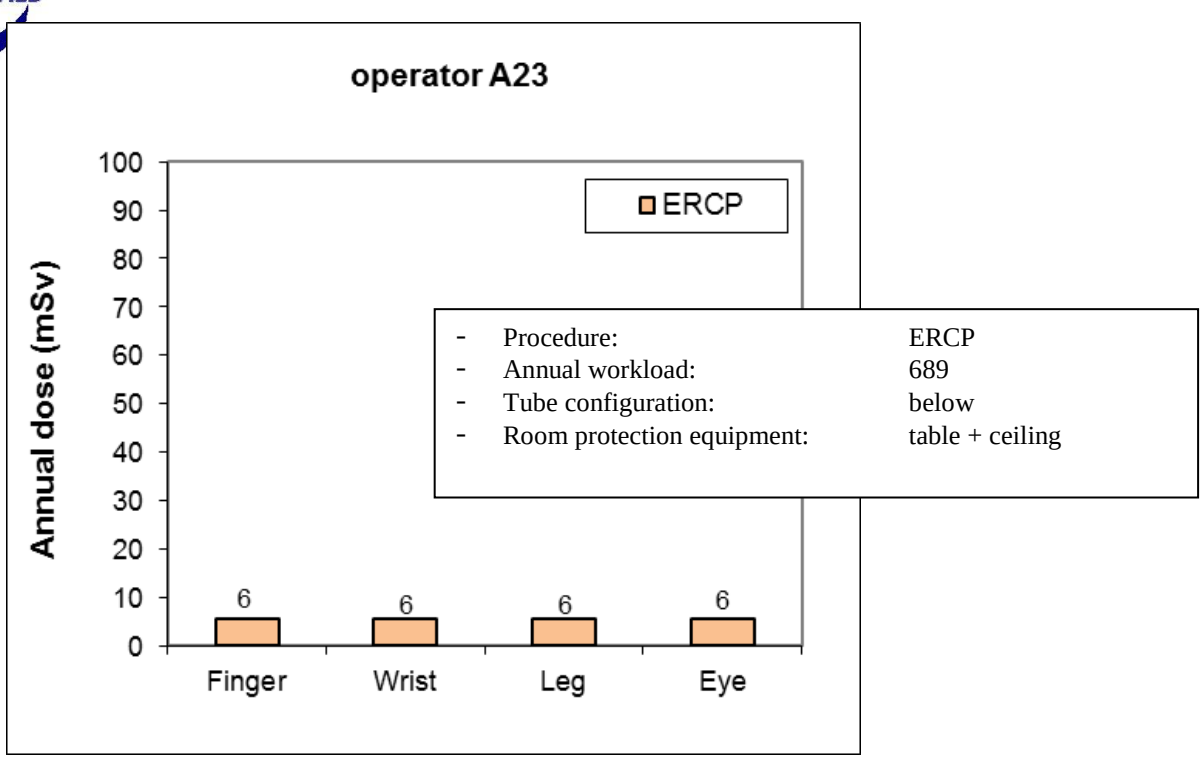


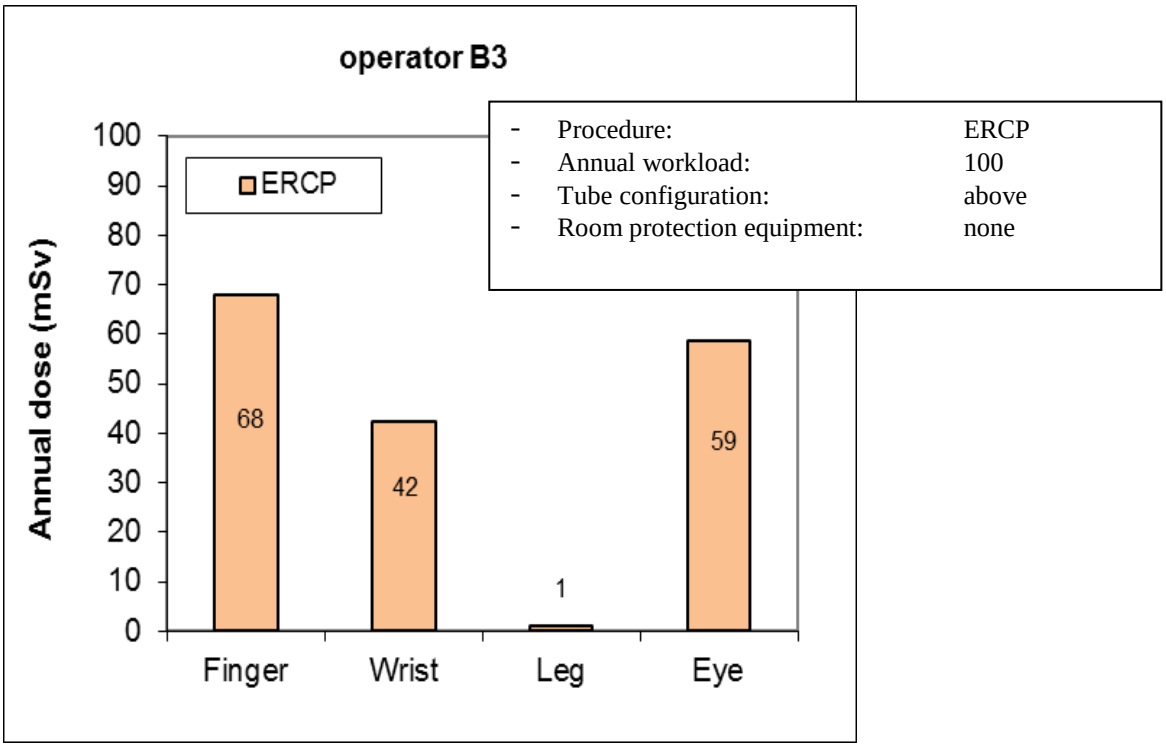
100 ERCP

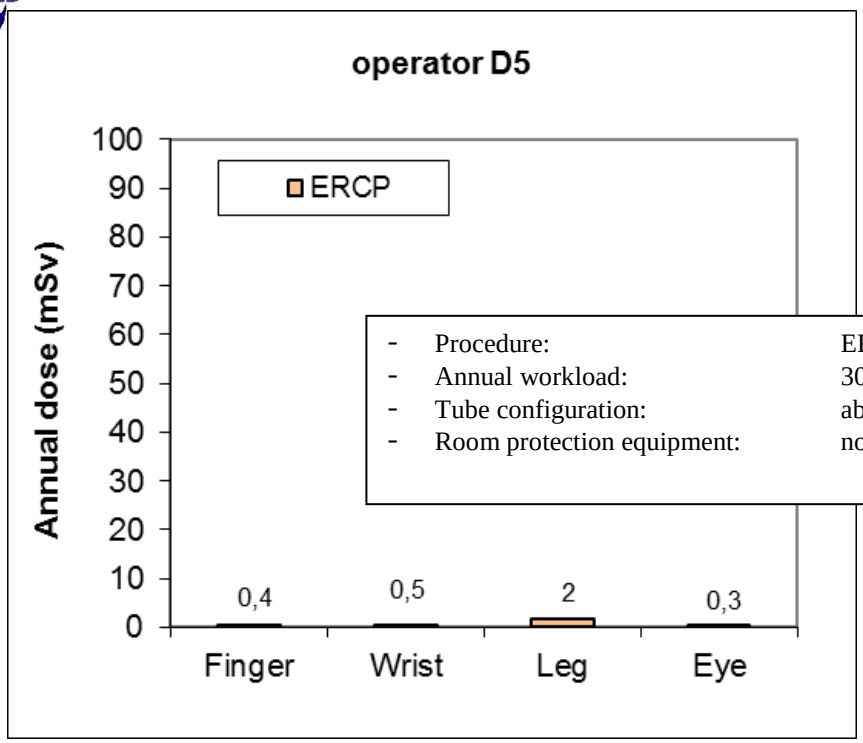
5 meas.

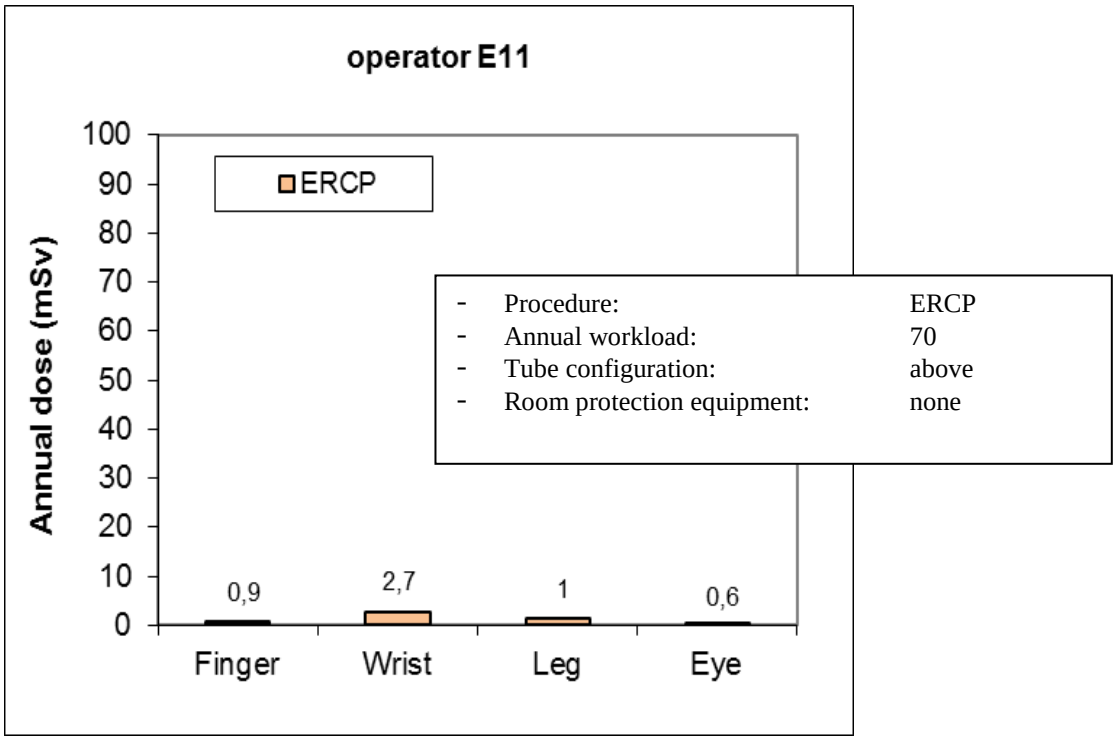


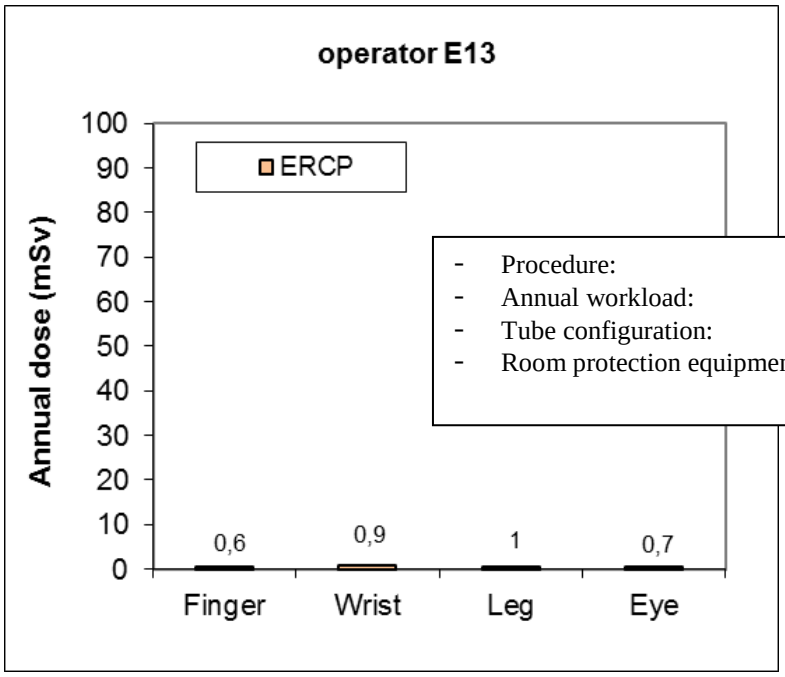
- Procedure: ERCP
- Annual workload: 1281
- Tube configuration: below
- Room protection equipment: table + ceiling


operator A23
Annual dose (mSv)
100
90
80
70
60
50
40
30
20
10
0
ERCP
6
6
6
6
Finger
Wrist
Leg
Eye
- Procedure: ERCP
- Annual workload: 689
- Tube configuration: below
- Room protection equipment: table + ceiling

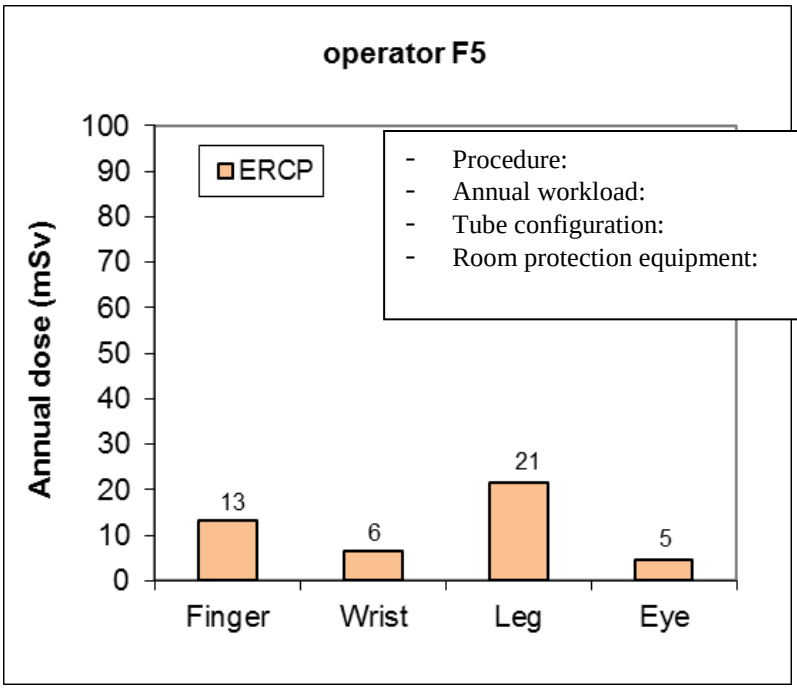

operator B3
Annual dose (mSv)
100
90
80
70
60
50
40
30
20
10
0
ERCP
68
42
1
59
Finger
Wrist
Leg
Eye
- Procedure: ERCP
- Annual workload: 100
- Tube configuration: above
- Room protection equipment: none


operator D5
Annual dose (mSv)
100
90
80
70
60
50
40
30
20
10
0
ERCP
0,4
0,5
2
0,3
Finger
Wrist
Leg
Eye
- Procedure: ERCP
- Annual workload: 30
- Tube configuration: above
- Room protection equipment: none


operator E11
Annual dose (mSv)
100
90
80
70
60
50
40
30
20
10
0
ERCP
0,9
2,7
1
0,6
Finger
Wrist
Leg
Eye
- Procedure: ERCP
- Annual workload: 70
- Tube configuration: above
- Room protection equipment: none

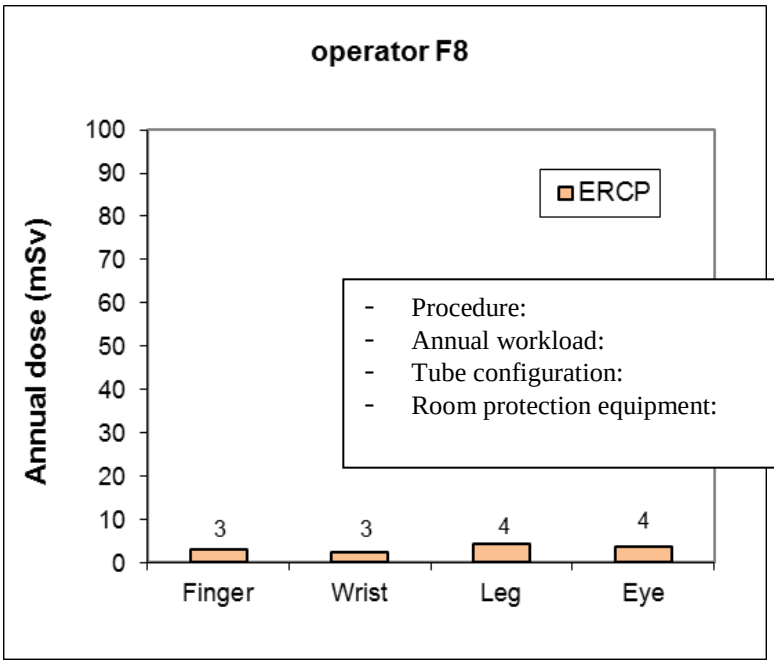


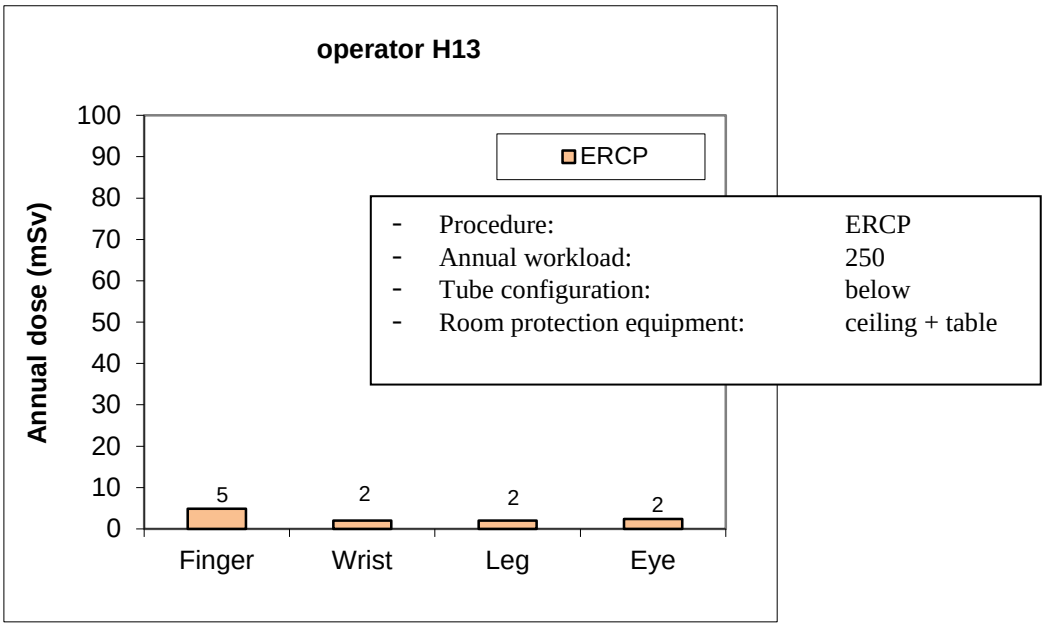
- Procedure: ERCP
- Annual workload: 70
- Tube configuration: above
- Room protection equipment: none



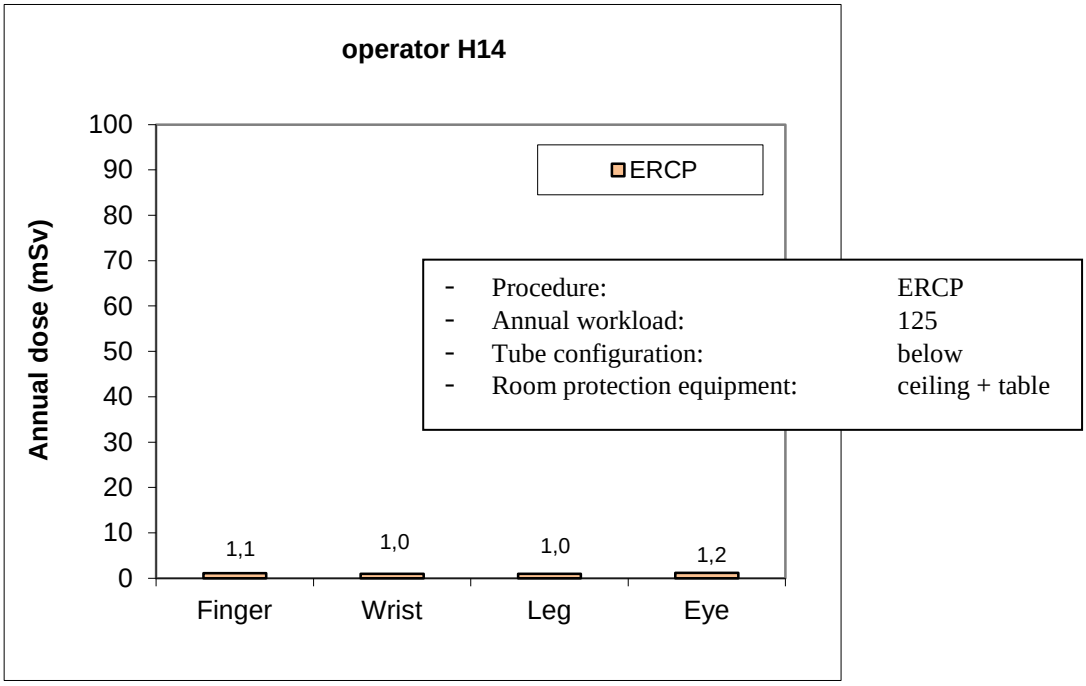
- Procedure: ERCP
- Annual workload: 107
- Tube configuration: below
- Room protection equipment: none

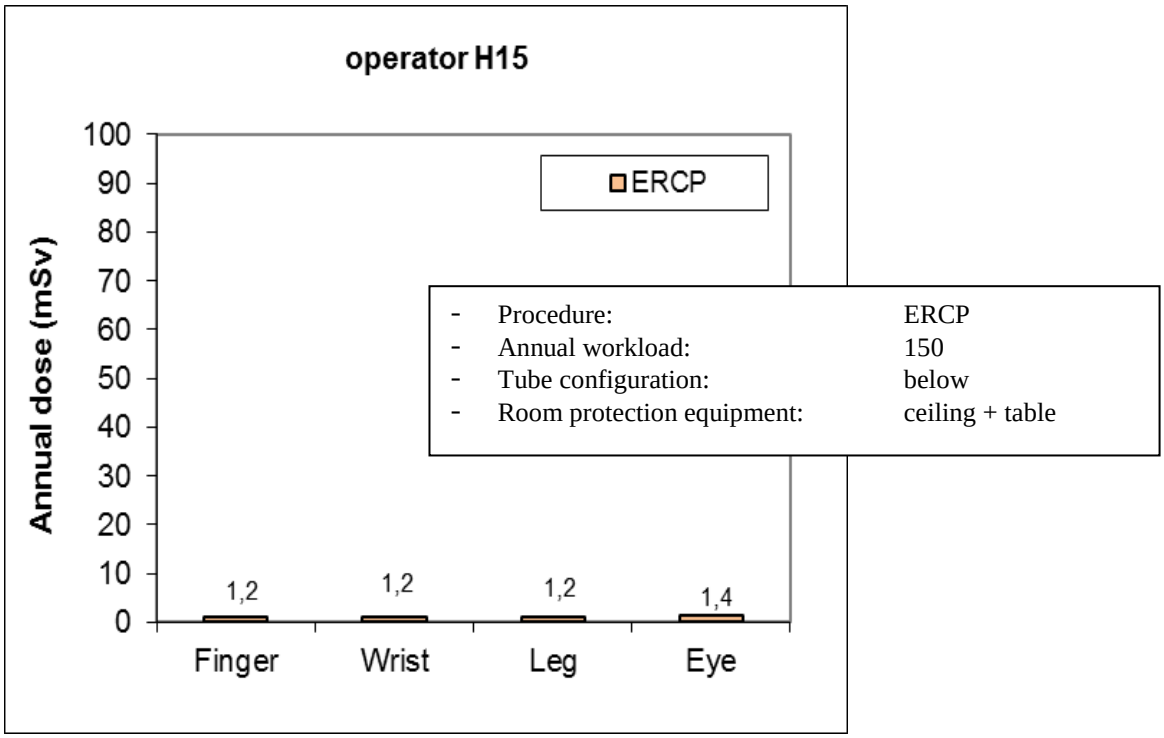
APPENDIX 2


operator F8
Annual dose (mSv)
100
90
80
70
60
50
40
30
20
10
0
ERCP
3
3
4
4
Finger
Wrist
Leg
Eye
- Procedure: ERCP
- Annual workload: 107
- Tube configuration: below
- Room protection equipment: none

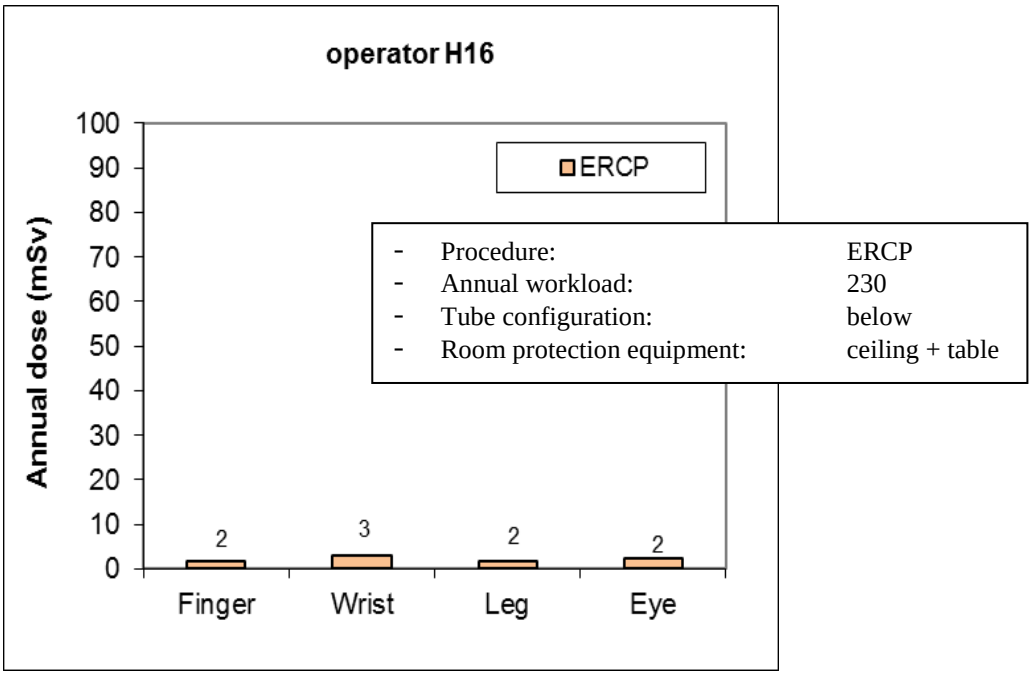

operator H13
Annual dose (mSv)
100
90
80
70
60
50
40
30
20
10
0
ERCP
5
2
2
2
Finger
Wrist
Leg
Eye
- Procedure: ERCP
- Annual workload: 250
- Tube configuration: below
- Room protection equipment: ceiling + table

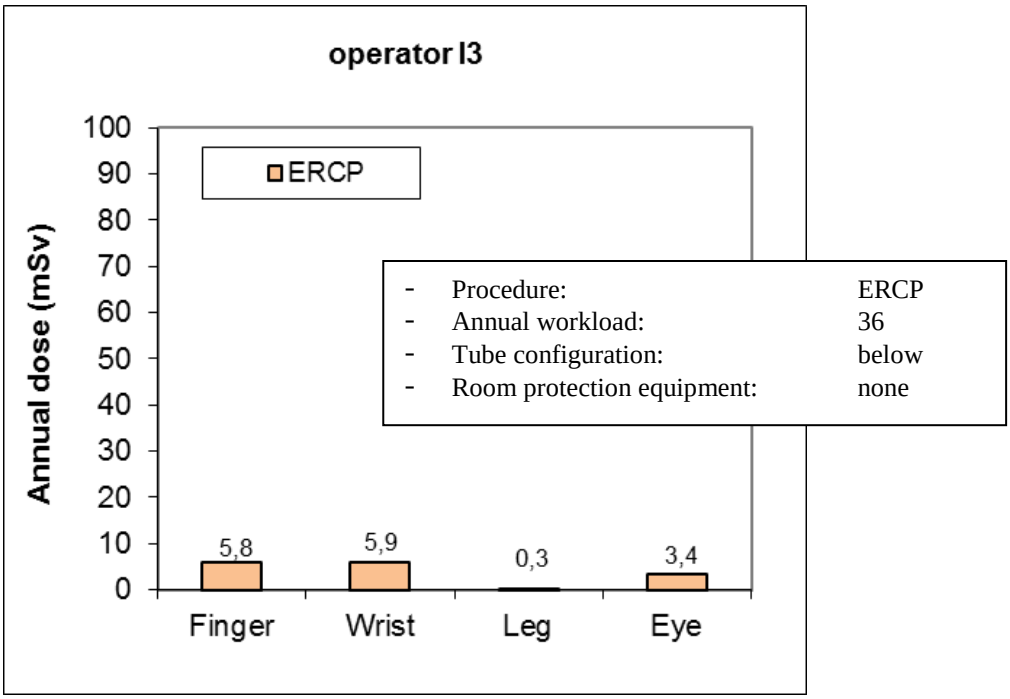
APPENDIX 2


operator H14
Annual dose (mSv)
100
90
80
70
60
50
40
30
20
10
0
ERCP
1,1
1,0
1,0
1,2
Finger
Wrist
Leg
Eye
- Procedure: ERCP
- Annual workload: 125
- Tube configuration: below
- Room protection equipment: ceiling + table

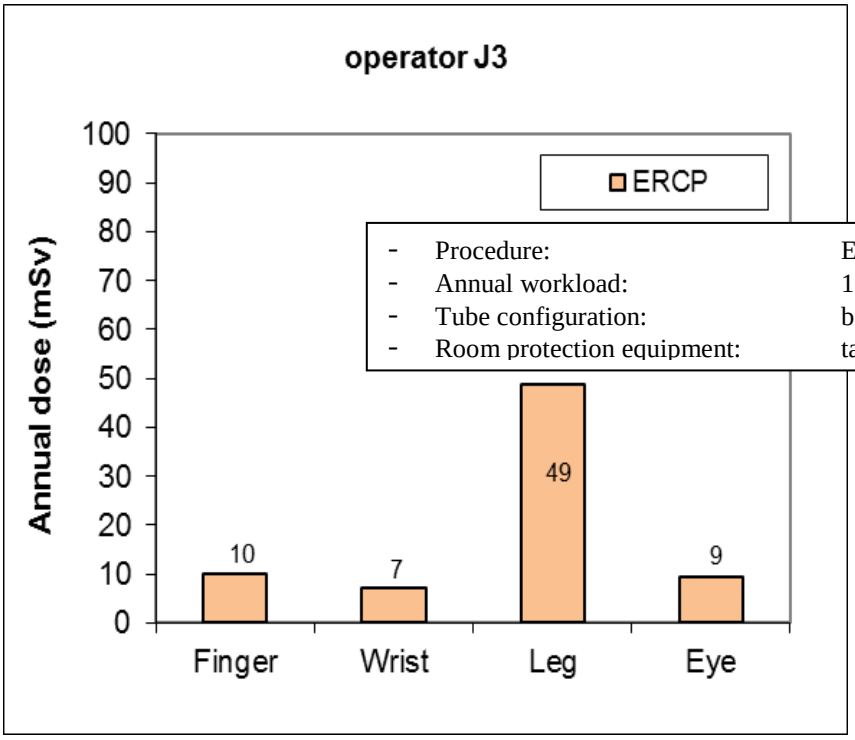

operator H15
Annual dose (mSv)
100
90
80
70
60
50
40
30
20
10
0
ERCP
1,2
1,2
1,2
1,4
Finger
Wrist
Leg
Eye
- Procedure: ERCP
- Annual workload: 150
- Tube configuration: below
- Room protection equipment: ceiling + table

APPENDIX 2

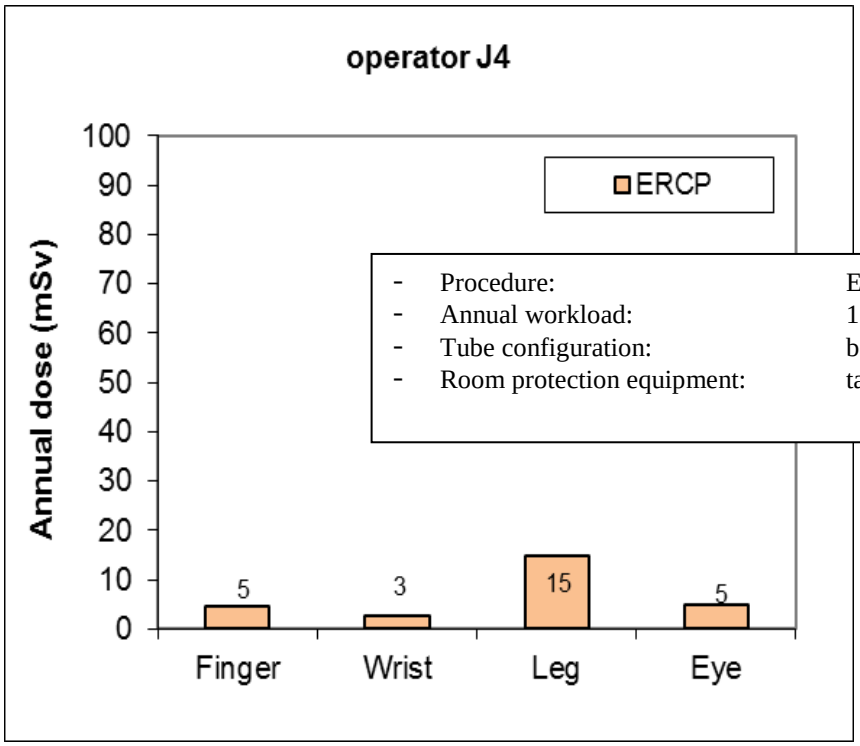

operator H16
Annual dose (mSv)
100
90
80
70
60
50
40
30
20
10
0
ERCP
2
3
2
2
Finger
Wrist
Leg
Eye
- Procedure: ERCP
- Annual workload: 230
- Tube configuration: below
- Room protection equipment: ceiling + table


operator I3
Annual dose (mSv)
100
90
80
70
60
50
40
30
20
10
0
ERCP
5,8
5,9
0,3
3,4
Finger
Wrist
Leg
Eye
- Procedure: ERCP
- Annual workload: 36
- Tube configuration: below
- Room protection equipment: none

APPENDIX 2

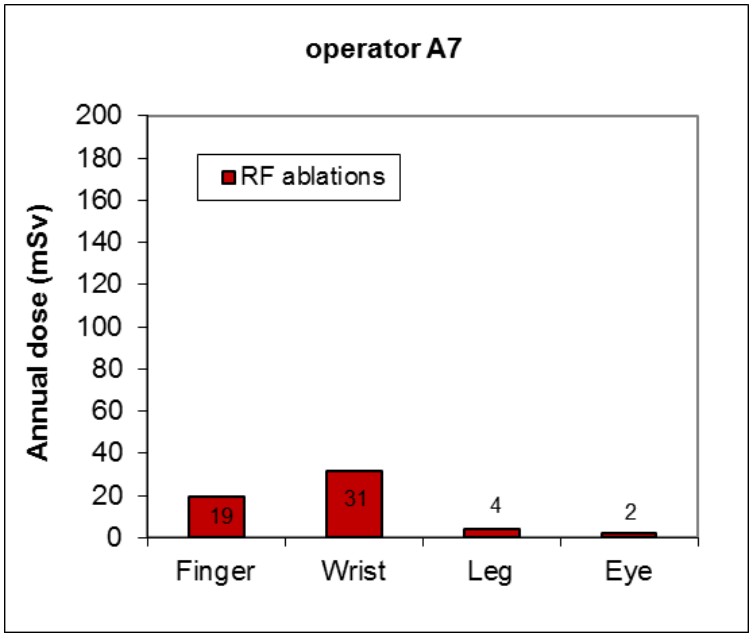


- Procedure: ERCP
- Annual workload: 150
- Tube configuration: below
- Room protection equipment: table (not well positioned)

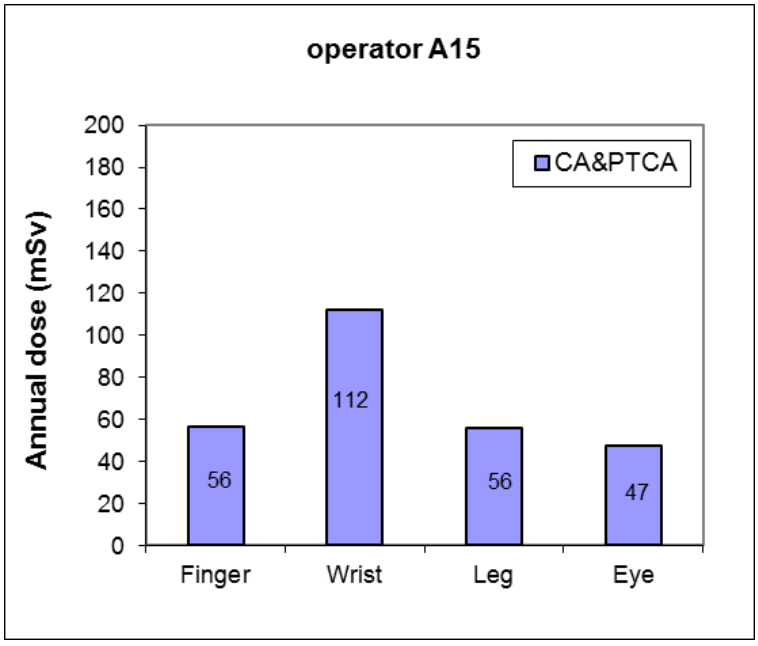


- Procedure: ERCP
- Annual workload: 150
- Tube configuration: below
- Room protection equipment: table (not well positioned)

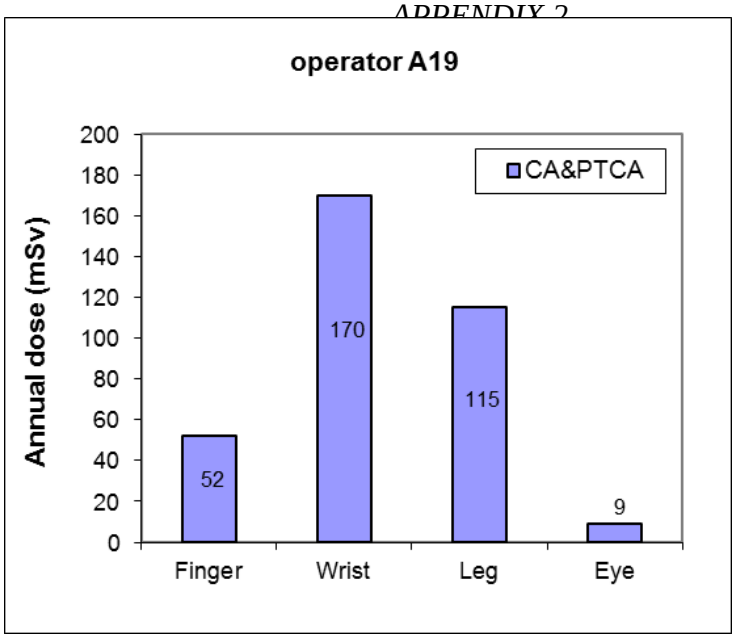
3. Graphs representing the annual doses for interventional cardiology procedures



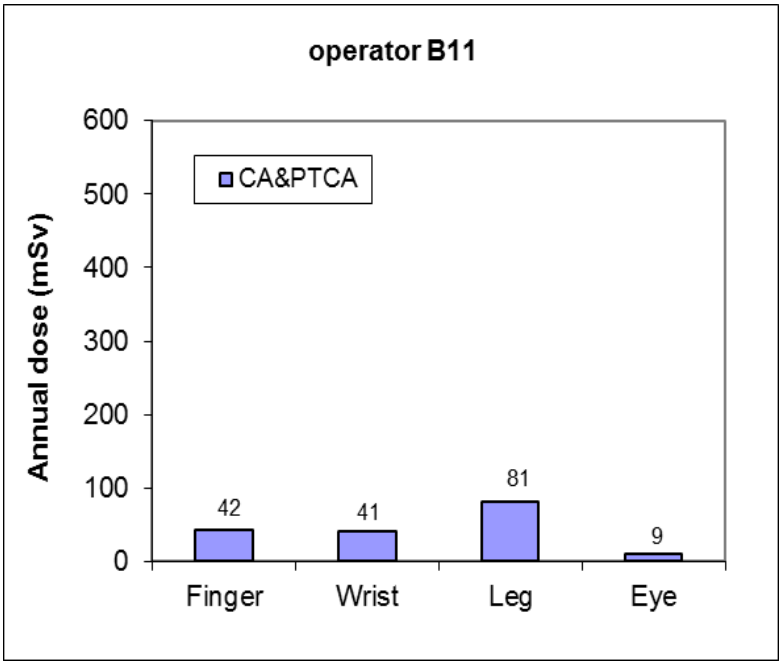
- Procedure: RF ablations
- Annual workload: 160
- Tube configuration: bi-plane
- Room protection equipment: RP cabin



- Procedure: CA & PTCA
- Annual workload: 750
- Tube configuration: bi-plane
- Room protection equipment: table + ceiling

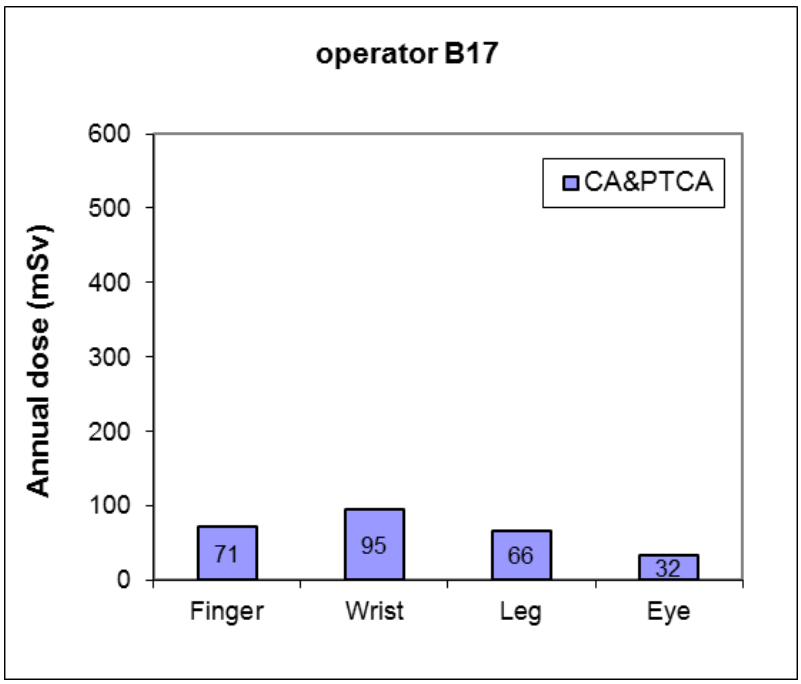


- Procedure: CA & PTCA
- Annual workload: 600
- Tube configuration: bi-plane
- Room protection equipment: table + ceiling

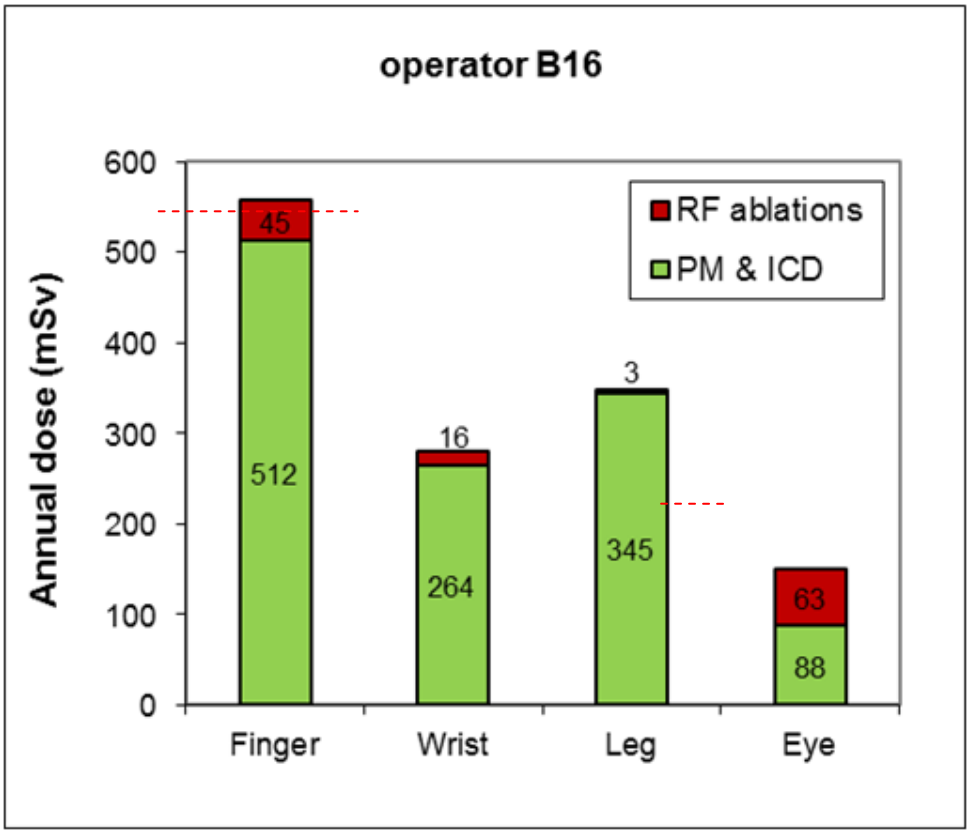


- Procedure: CA & PTCA
- Annual workload: 255
- Tube configuration: below / bi-plane
- Room protection equipment: none / table + ceiling

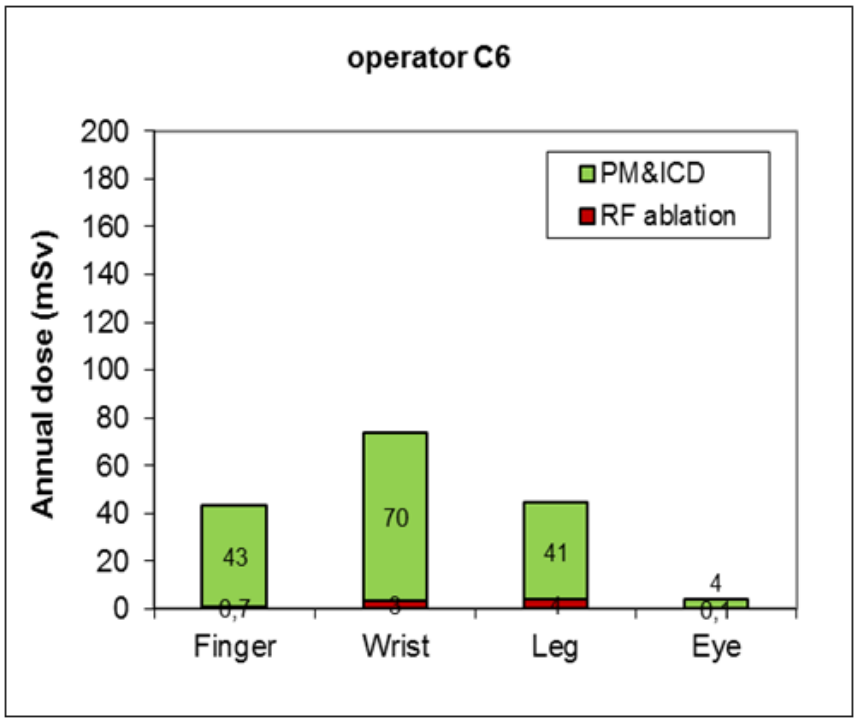
APPENDIX 2



-	Procedure:	CA & PTCA
-	Annual workload:	233
-	Tube configuration:	bi-plane
-	Room protection equipment:	table + ceiling

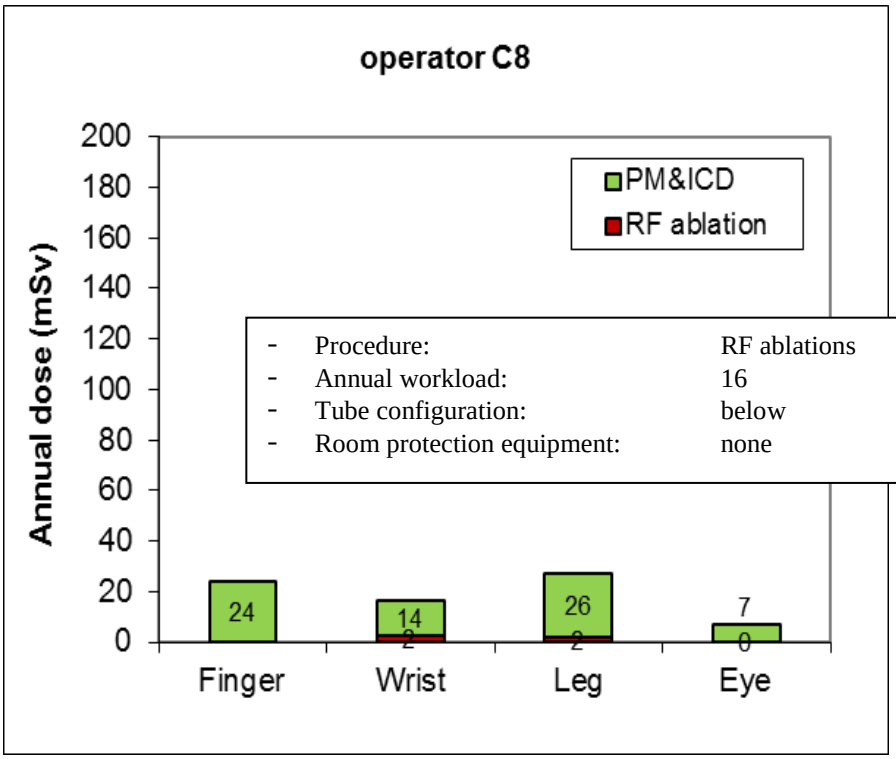


-	Procedure:	RF ablations	PM & ICD
-	Annual workload:	61	151
-	Tube configuration:	below	below
-	Room protection equipment:	table	none

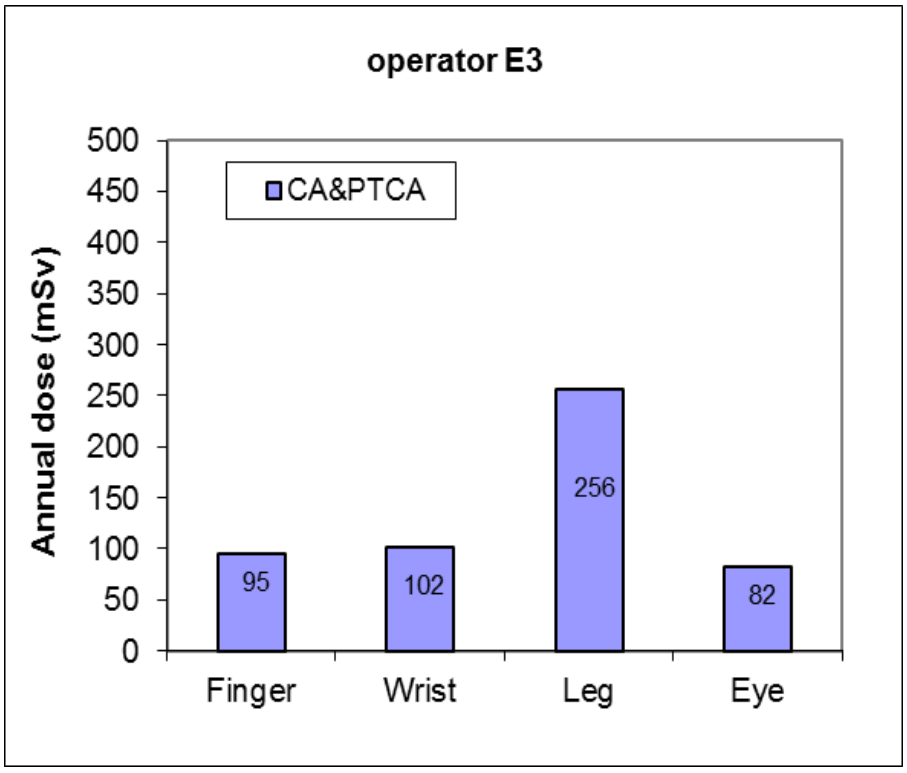


-	Procedure:	RF ablations	PM & ICD
-	Annual workload:	16	40
-	Tube configuration:	below	below
-	Room protection equipment:	none	none

APPENDIX 2

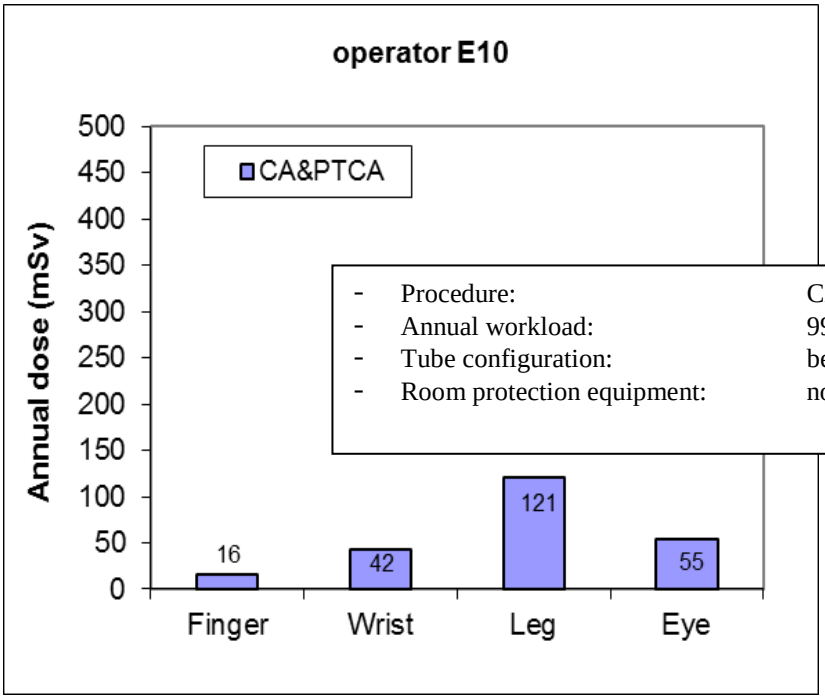


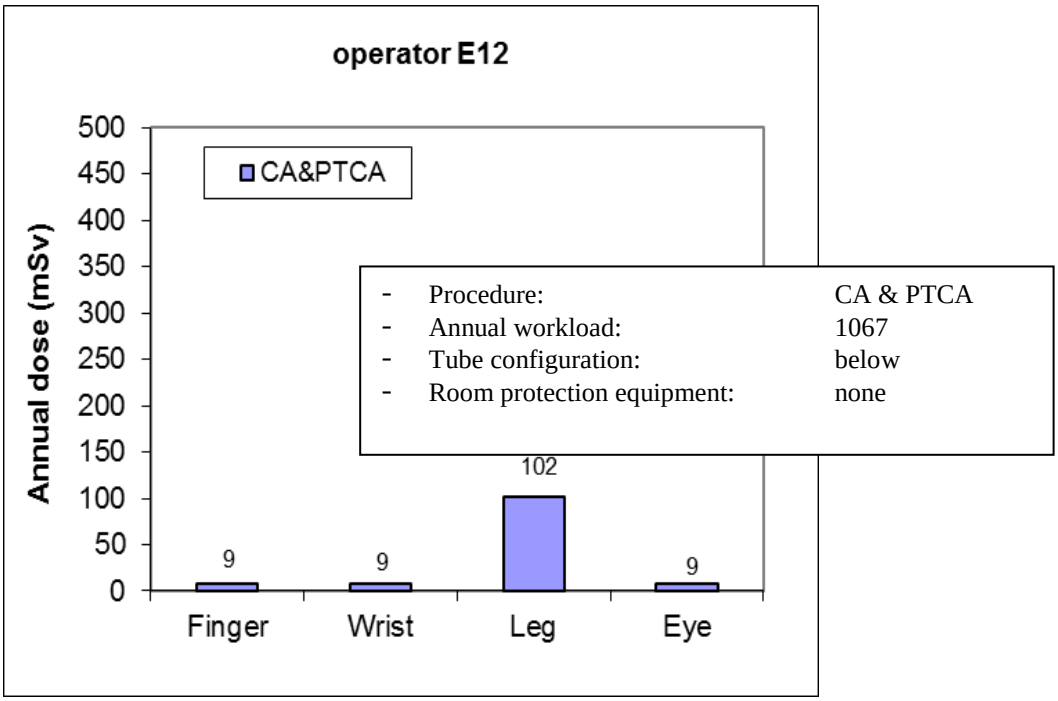
-	Procedure:	RF ablations	PM & ICD
-	Annual workload:	16	40
-	Tube configuration:	below	below
-	Room protection equipment:	none	none



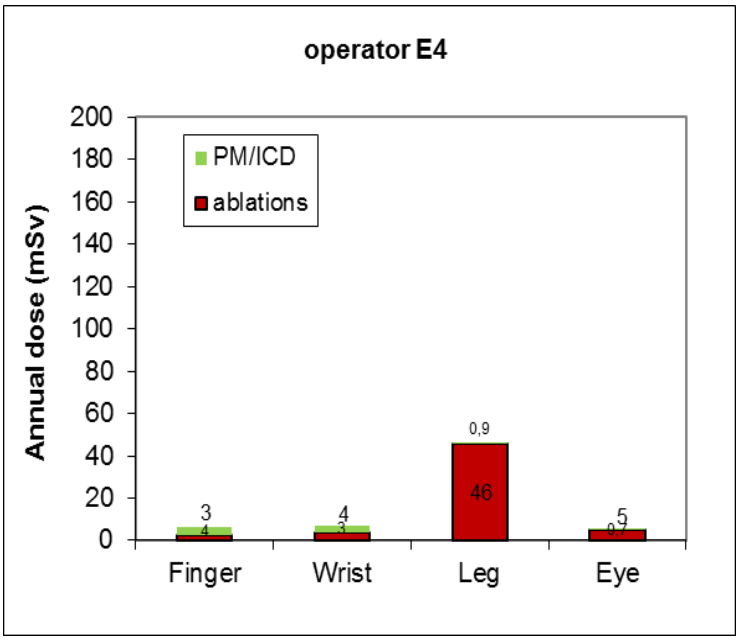
-	Procedure:	CA & PTCA
-	Annual workload:	1157
-	Tube configuration:	below
-	Room protection equipment:	table

APPENDIX 2

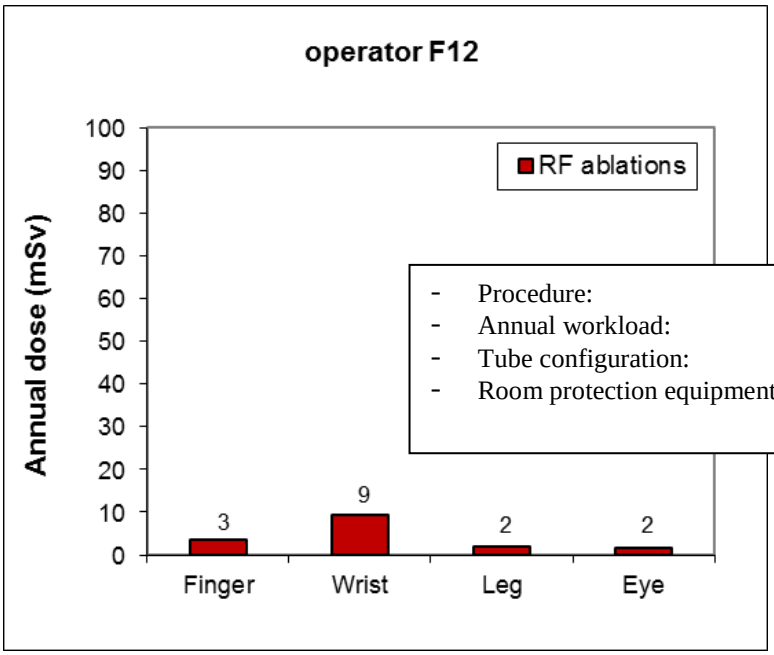

operator E10
Annual dose (mSv)
500
450
400
350
300
250
200
150
100
50
0
CA&PTCA
16
42
121
55
Finger
Wrist
Leg
Eye
- Procedure: CA & PTCA
- Annual workload: 998
- Tube configuration: below
- Room protection equipment: none


operator E12
Annual dose (mSv)
500
450
400
350
300
250
200
150
100
50
0
CA&PTCA
9
9
102
9
Finger
Wrist
Leg
Eye
- Procedure: CA & PTCA
- Annual workload: 1067
- Tube configuration: below
- Room protection equipment: none

APPENDIX 2

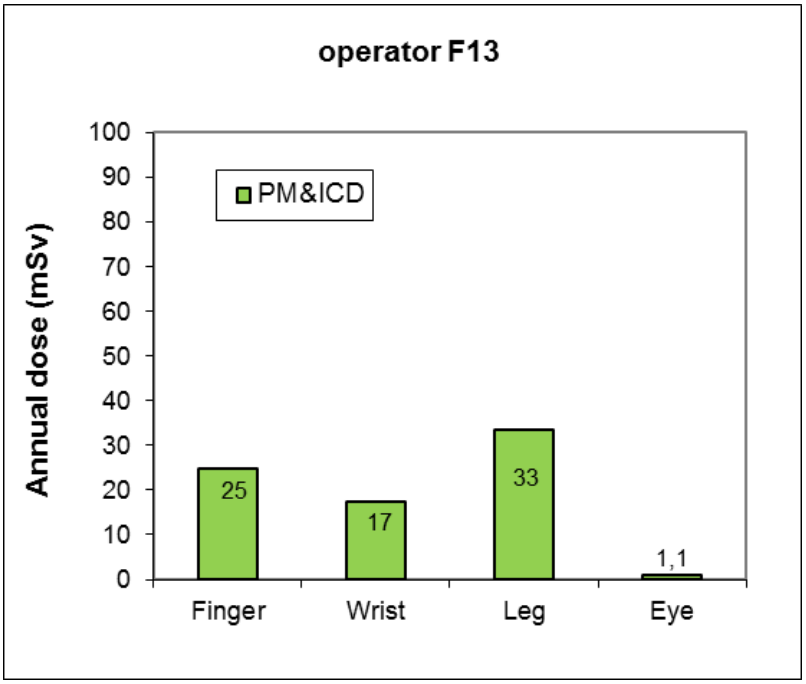


-	Procedure:	RF ablations	PM & ICD
-	Annual workload:	350	80
-	Tube configuration:	below	below
-	Room protection equipment:	none	none

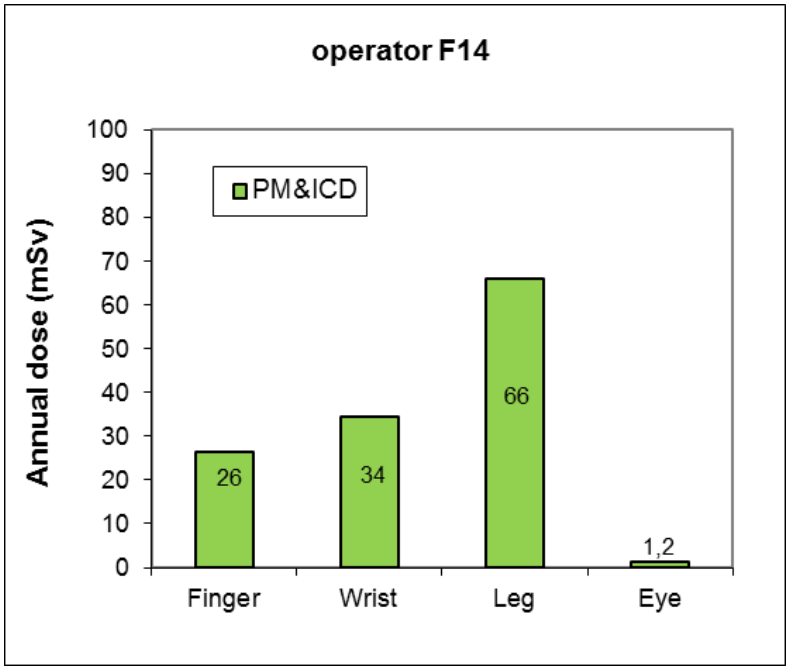


-	Procedure:	RF ablations
-	Annual workload:	183
-	Tube configuration:	below
-	Room protection equipment:	table + ceiling

APPENDIX 2

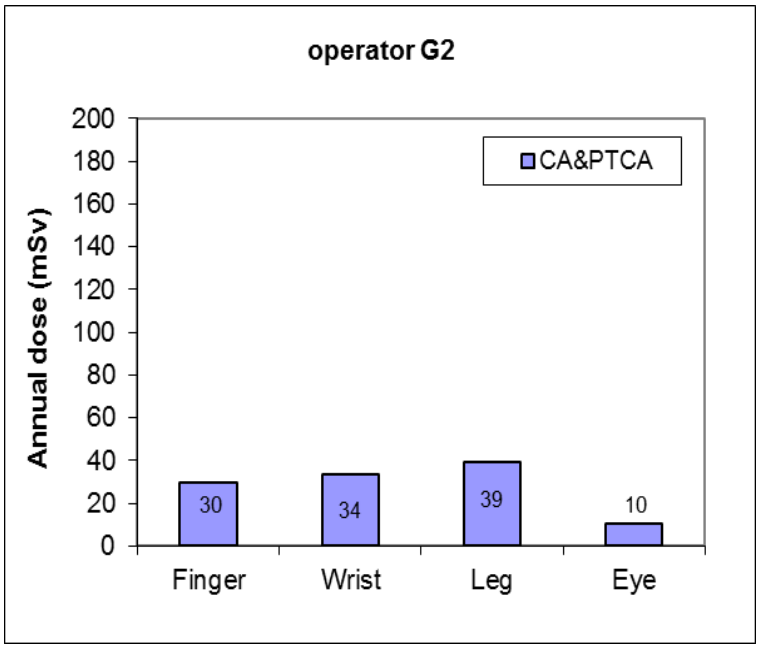


-	Procedure:	PM & ICD
-	Annual workload:	44
-	Tube configuration:	below
-	Room protection equipment:	none

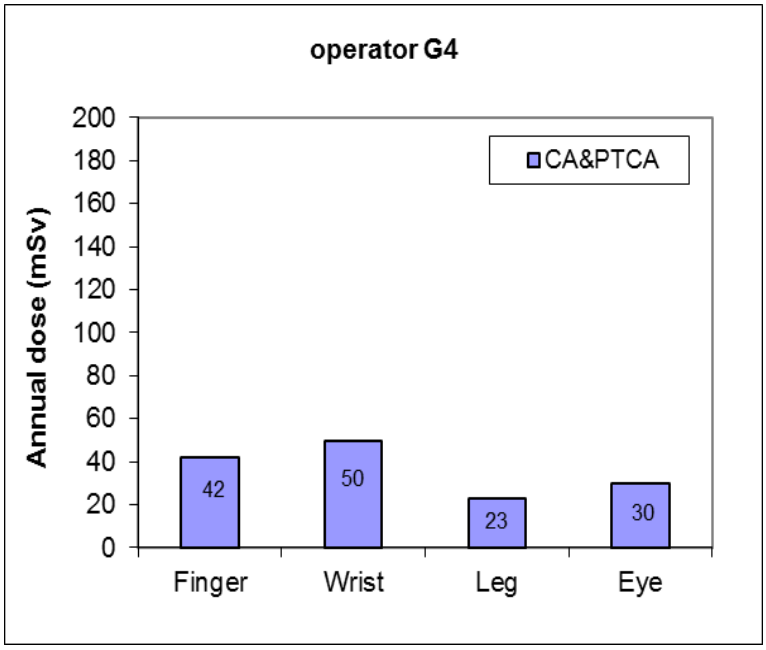


-	Procedure:	PM & ICD
-	Annual workload:	144
-	Tube configuration:	below
-	Room protection equipment:	none

APPENDIX 2

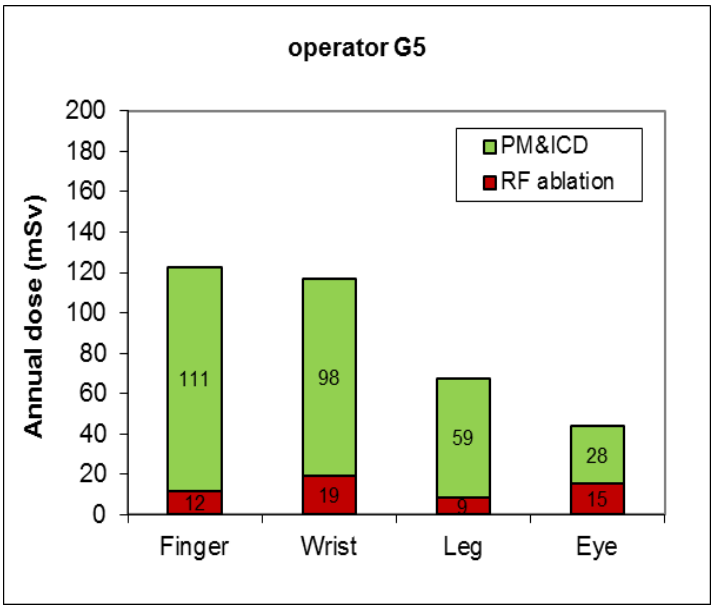


- Procedure: CA & PTCA
- Annual workload: 714
- Tube configuration: below
- Room protection equipment: table + ceiling

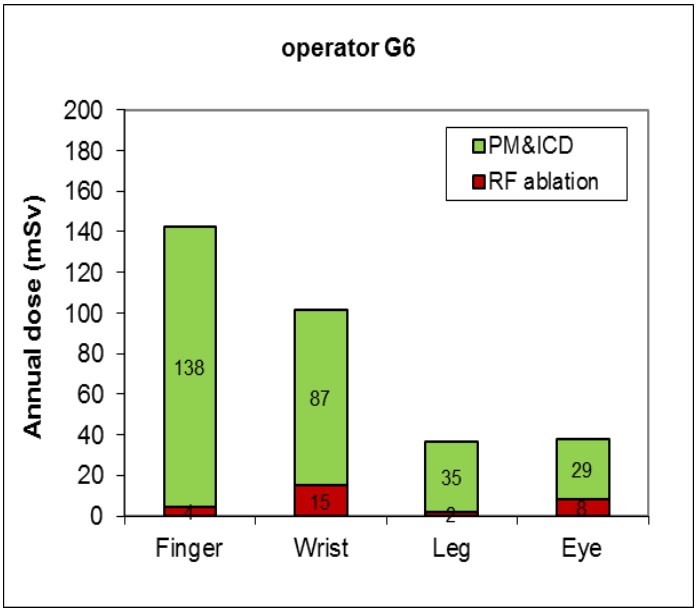


- Procedure: CA & PTCA
- Annual workload: 904
- Tube configuration: below
- Room protection equipment: table + ceiling

APPENDIX 2

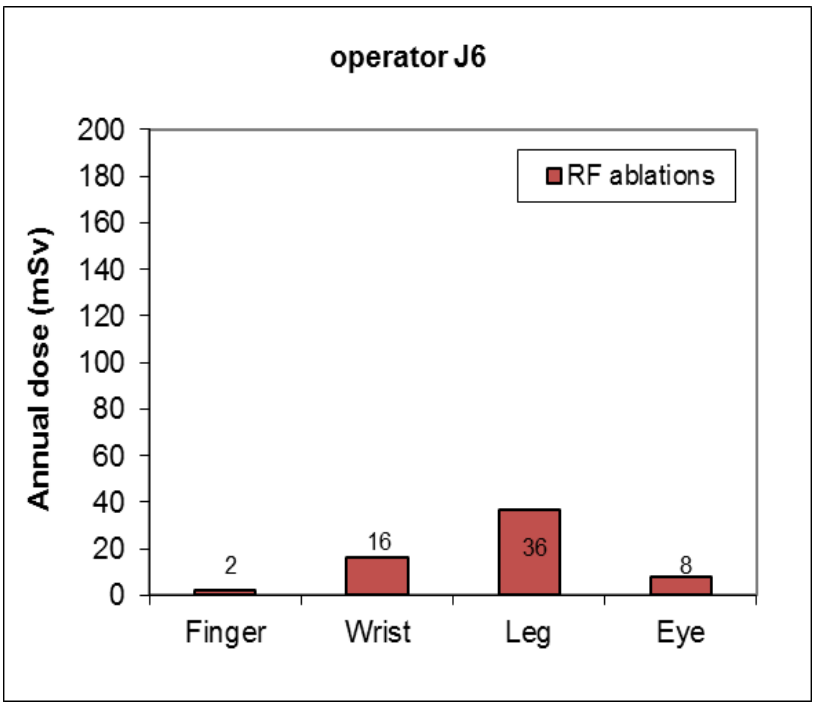


-	Procedure:	RF ablations	PM & ICD
-	Annual workload:	189	185
-	Tube configuration:	below	below
-	Room protection equipment:	table + ceiling	table

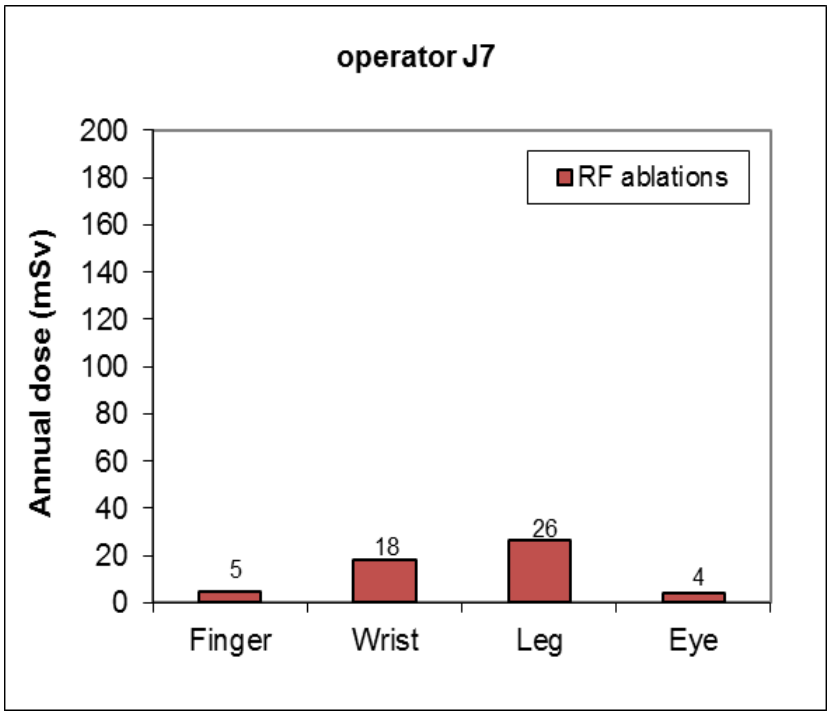


-	Procedure:	RF ablations	PM & ICD
-	Annual workload:	187	88
-	Tube configuration:	below	below
-	Room protection equipment:	table + ceiling	table

APPENDIX 2

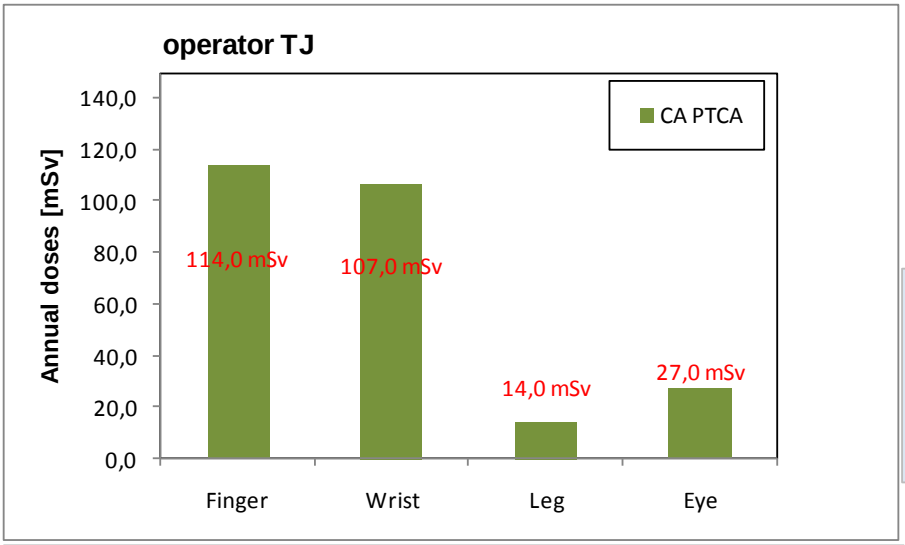


- Procedure: RF ablations
- Annual workload: 209
- Tube configuration: below
- Room protection equipment: RP cabin + table + ceiling



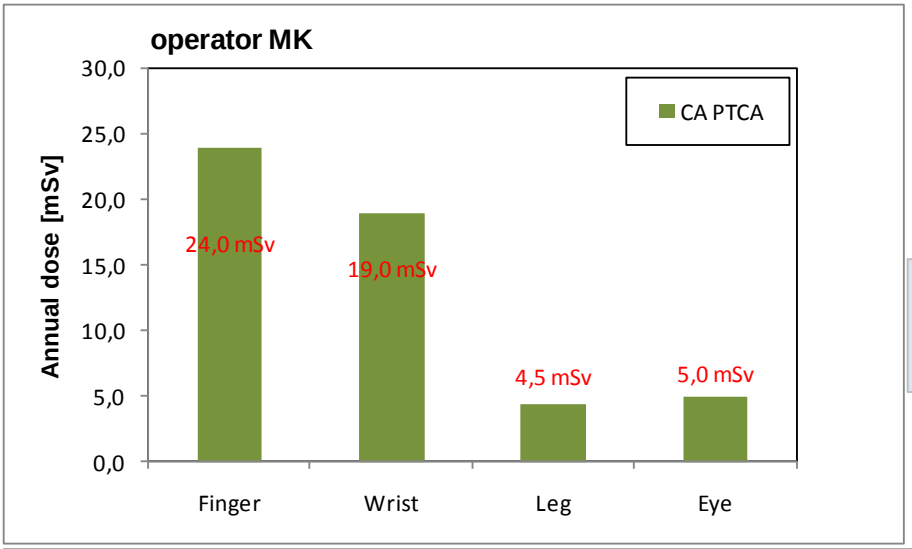
- Procedure: RF ablations
- Annual workload: 60
- Tube configuration: below
- Room protection equipment: table + ceiling

APPENDIX 2



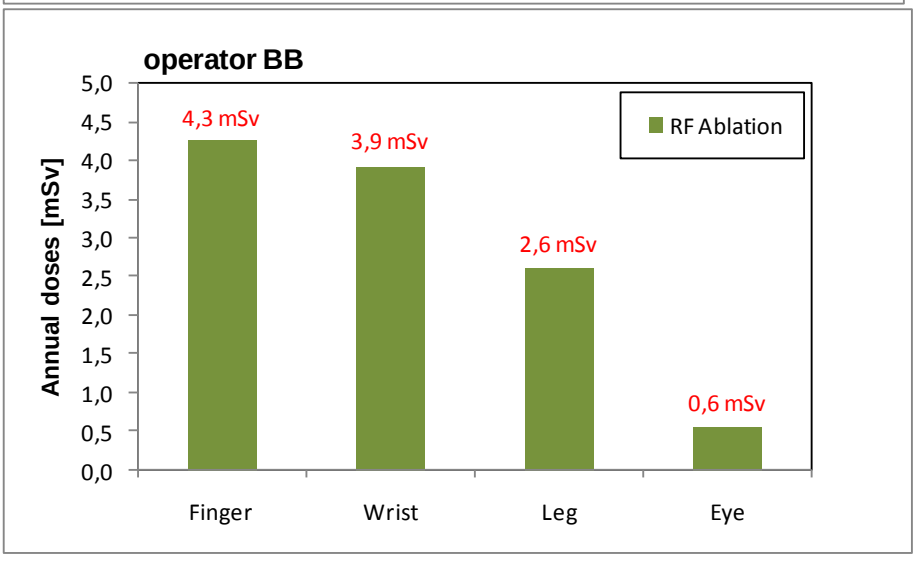
Protective equipment:
* table shield
* ceiling suspended lead glass

1000 CA PTCA / year



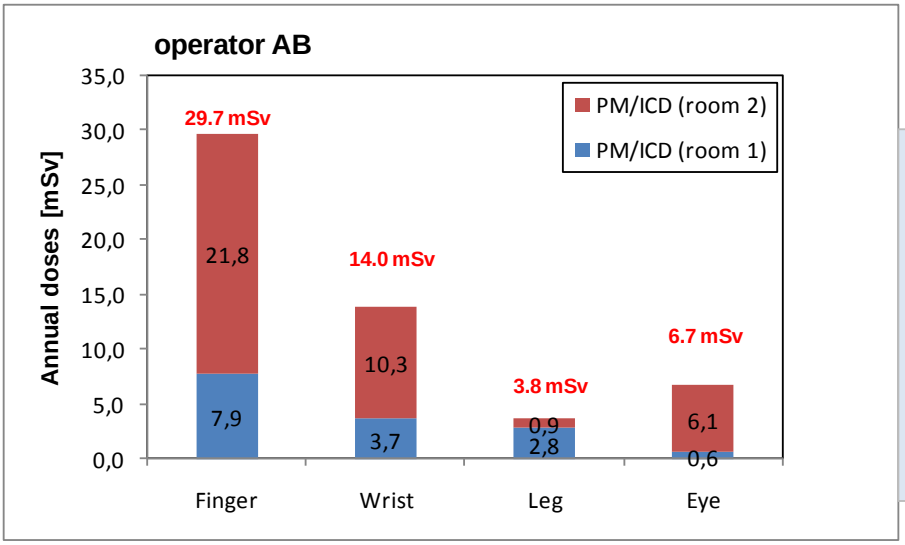
Protective equipment:
* table shield

500 CA PTCA / year



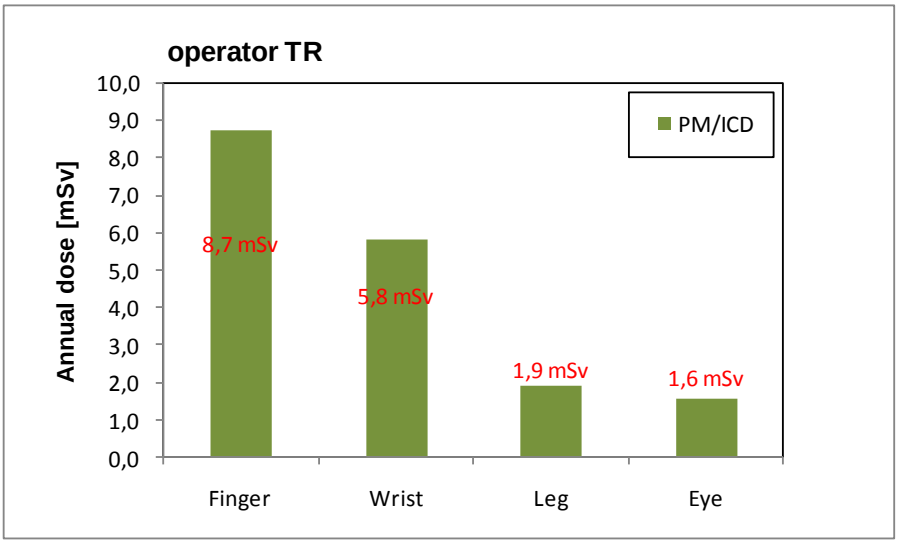
Protective equipment:
* table shield
* sometimes ceiling shield

70 RF Ablations / year



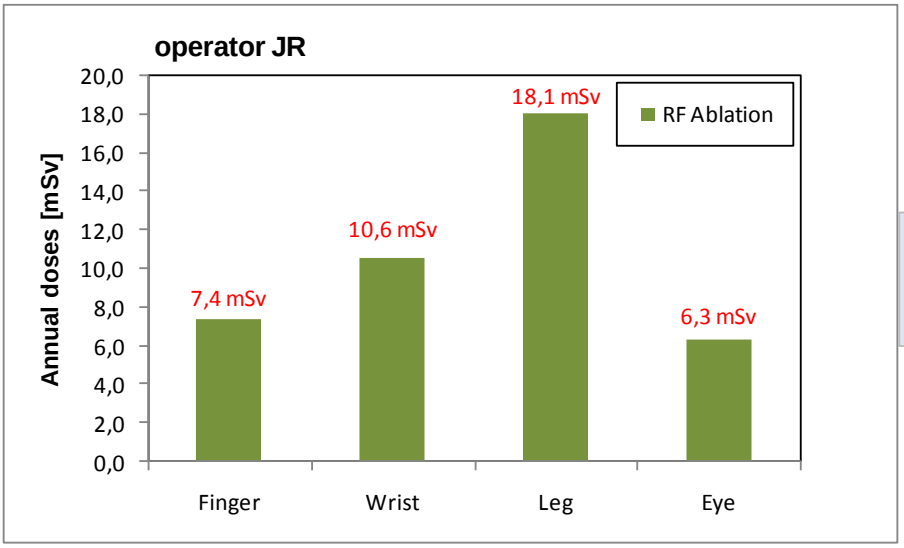
room 1 (24 ICD/year):
* protective equipment: none
* tube below

room 2 (104 PM/year):
*protective equipment: none
*tube above

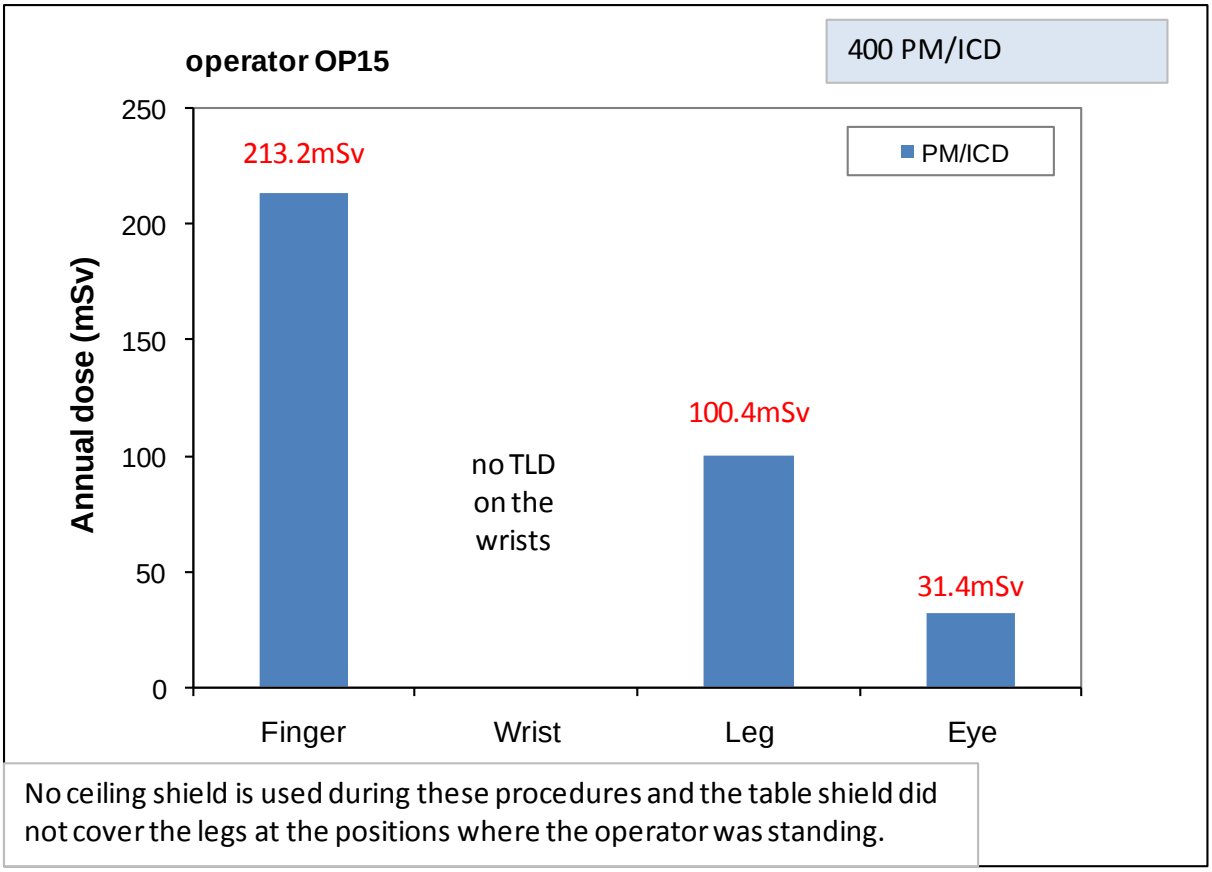


Protective equipment:
* table shield

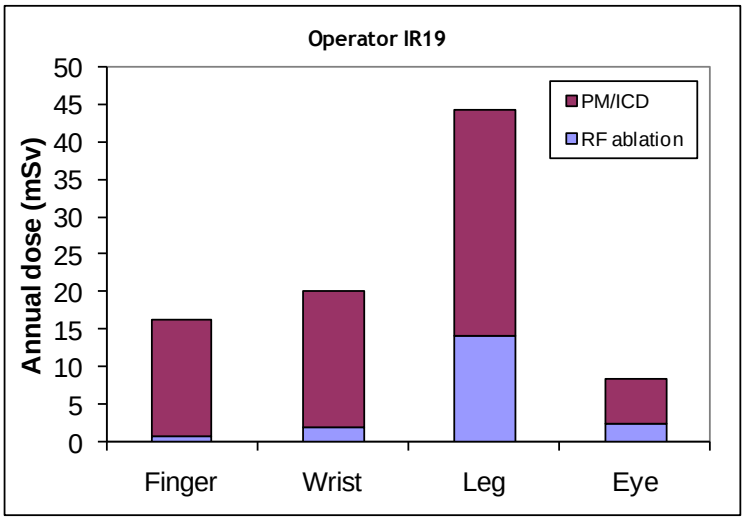
100 PM_ICD / year



Protective equipment:
* table shield
100 RF Ablations / year



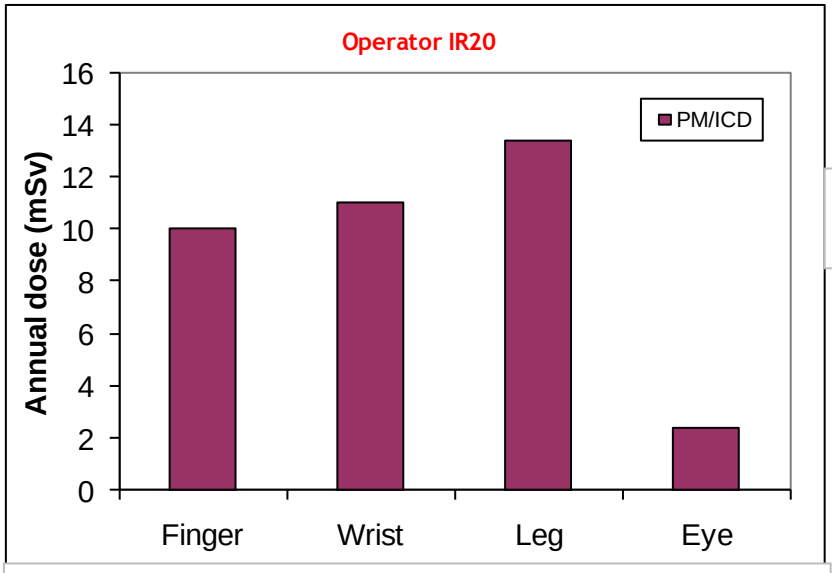
No ceiling shield is used during these procedures and the table shield did not cover the legs at the positions where the operator was standing.



65 RF A
100 PM/ICD

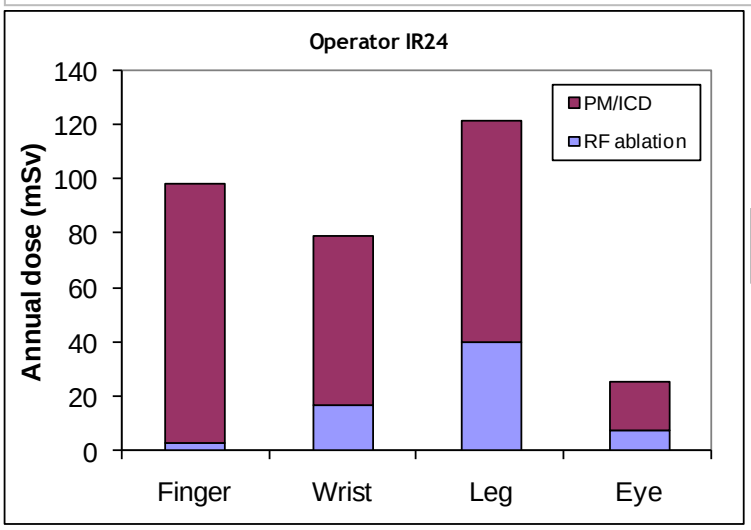
5 meas. For RF A and 4 for PM/ICD

APPENDIX 2



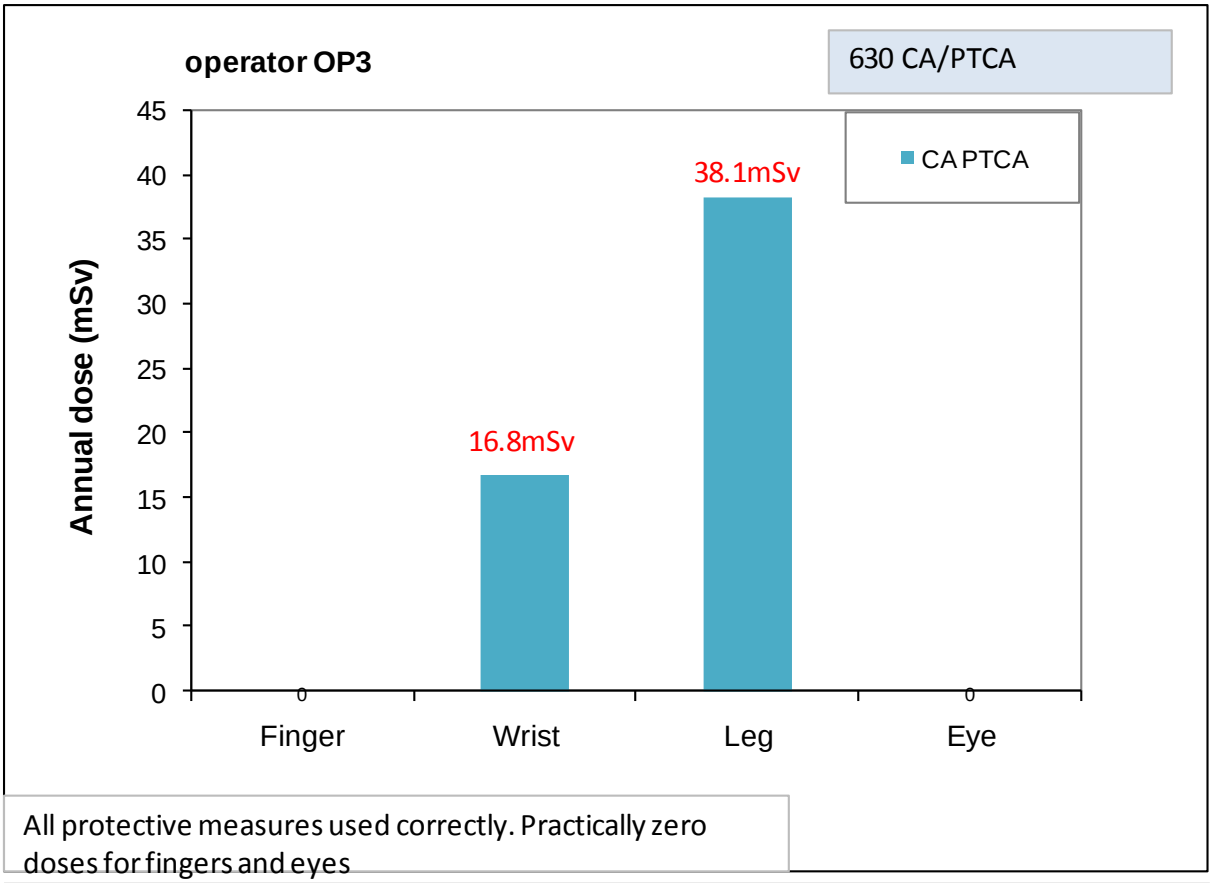
100 PM/ICD

IR20 performs 65 RF A per year also

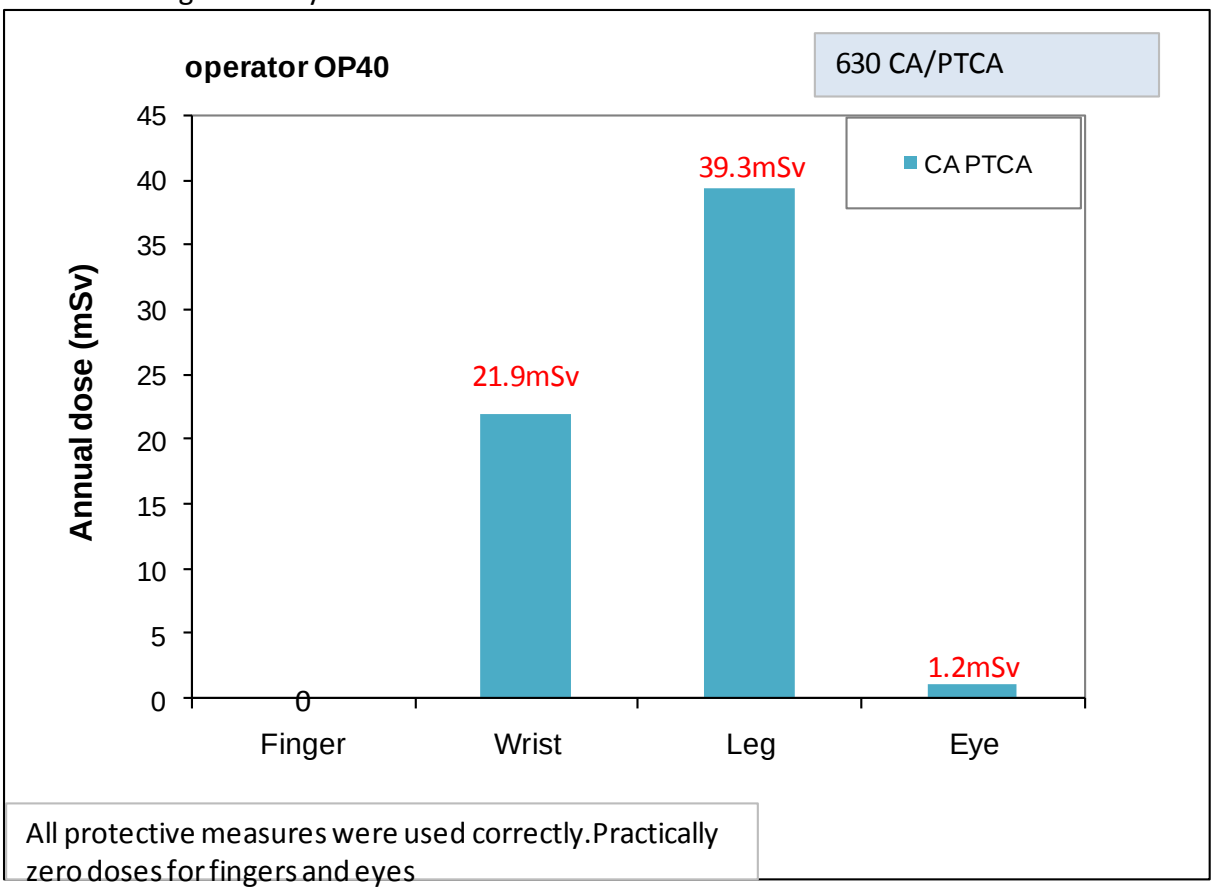


47 RF A
113 PM/ICD

9 meas. For RF A and 5 for PM/ICD

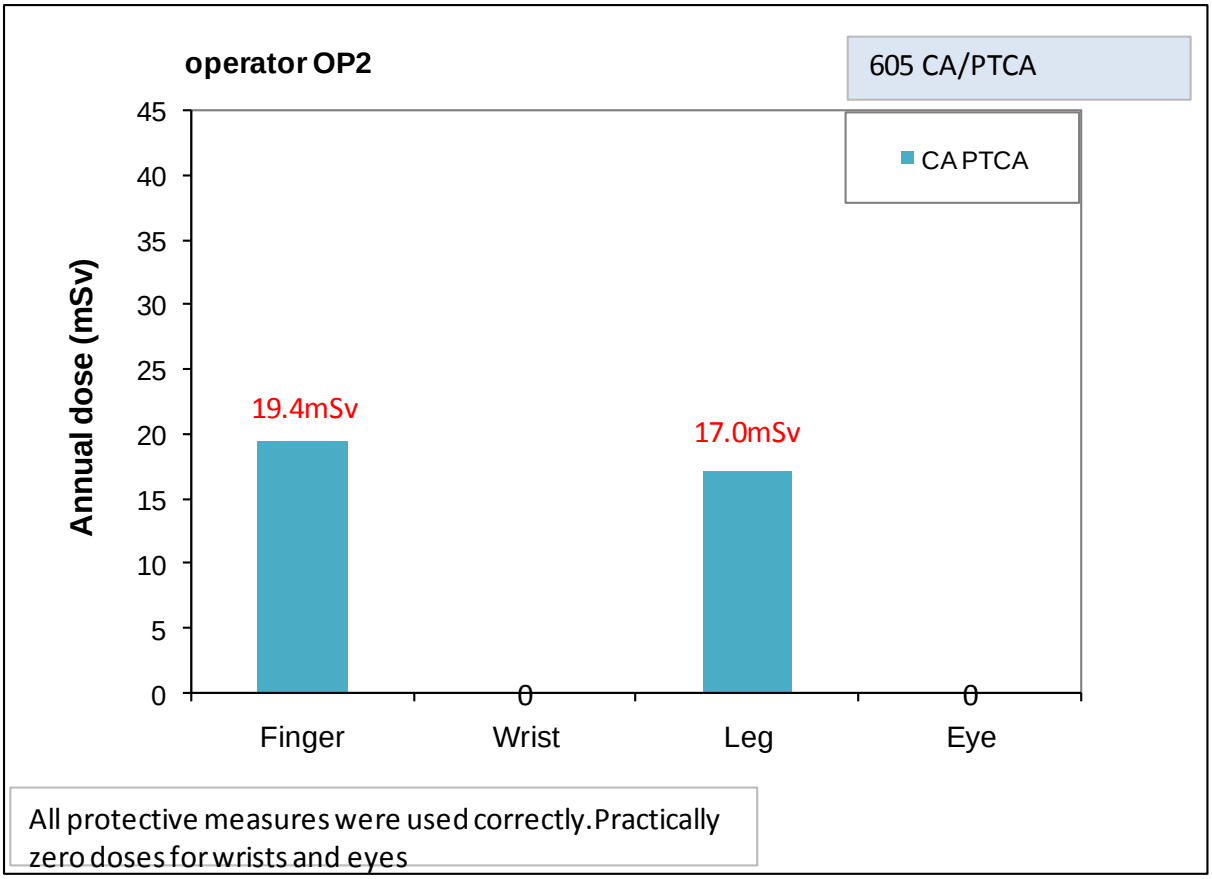


All protective measures used correctly. Practically zero doses for fingers and eyes



All protective measures were used correctly.Practically zero doses for fingers and eyes

APPENDIX 2


operator OP2
605 CA/PTCA
CA PTCA
Annual dose (mSv)
45
40
35
30
25
20
15
10
5
0
19.4mSv
17.0mSv
0
0
Finger
Wrist
Leg
Eye
All protective measures were used correctly. Practically zero doses for wrists and eyes