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THE EFFECT OF LEAD FREE CAP ON THE DOSES OF IONIZING RADIATION TO THE HEAD OF INTERVENTIONAL CARDIOLOGISTS WORKING IN HAEMODYNAMIC ROOM

WŁODZIMIERZ GRABOWICZ[1], KONRAD MASIAREK[1], TOMASZ GÓRNIK[1], TOMASZ GRYCEWICZ[1], MARCIN BRODECKI[2], JÉRÉMIE DABIN[3], CHRISTELLE HUET[4], FILIP VANHAVERE[3] and JOANNA K. DOMIENIK-ANDRZEJEWSKA[2]

[1] Medical University of Lodz, Łódź, Poland
Department of Interventional Cardiology and Cardiac Arrythmias
[2] Nofer Institute of Occupational Medicine, Łódź, Poland
Department of Radiation Protection
[3] Belgian Nuclear Research Centre, Mol, Belgium
[4] Institut de Radioprotection et de Sûreté Nucléaire (IRSN), Fontenay-aux Roses Cedex, France

Abstract
Objectives: The study aim was to analyse the influence of the lead free cap on doses received by interventional cardiologists. The impact of lead free cap on doses to the head were evaluated in number of studies. As different methods used to assess the attenuation properties of protective cap can lead to ambiguous results, a detailed study was performed. **Material and Methods:** The effectiveness of a lead free cap in reducing the doses to the skin was assessed in clinic by performing measurements with thermoluminescent dosimeters attached inside and outside the cap first during individual coronary angiography (CA) or CA/percutaneous transluminal coronary angioplasty (CA/PTCA) procedures and then cumulated during few procedures of the same type. In order to investigate the effect of the cap on reducing the doses to the brain additional measurements were performed with a male Alderson Rando and polymethyl methacrylate (PMMA) phantoms representing the physician and the patient, respectively for different projections. The brain dose per procedure, annual and cumulated during entire working practice were estimated for both cases working with and without the cap. **Results:** The dose reduction factor (RF) for the skin (the quotient of doses outside and inside the cap) vary from 1.1 up to 4.0 in clinical conditions; on average 2.3-fold reduction is observed in the most exposed left temple. The RFs determined for the part of the head covered by the cap range from 1.4 to 1.8 while for the brain from 1.0 to 1.1 depending on the projection. The estimated annual brain dose for interventional cardiologist performing yearly 550 CA/PTCA procedures without any protective shields is 7.2 mGy and it is reduced with the lead free cap by an average factor of 1.1. **Conclusions:** The study results proved the considerable effectiveness of lead free cap to protect the skin but very limited to protect the brain. Int J Occup Med Environ Health. 2022;35(5):549–60

Key words:
radiation protection, interventional cardiology, skin dose, lead free cap, brain dose, interventional physicians

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Corresponding author: Joanna K. Domienik-Andrzejewska, Nofer Institute of Occupational Medicine, Department of Radiation Protection, św. Teresy 8, 91-348 Łódź, Poland (e-mail: joanna.domienik@imp.lodz.pl).

INTRODUCTION

Epidemiological studies of the association between high doses of ionizing radiation and central nervous system tumors (NST) give rather consistent results. The significant dose-related excess risk of NST was confirmed in the previous and the most recent studies of atomic bomb survivors [1,2] and persons who received radiation treatment to the scalp during childhood [3–6]. Moreover, the effect of modification of the association of ionizing radiation and nervous system cancers by sex, age at exposure and the time since first exposure was examined. Generally, the excess risk decreased with increasing age at examination.

Regarding the low and moderate doses characteristic for medical and occupational exposure, it is not clear whether the ionizing radiation is a risk factor for NST or not, mainly due to the low number of the study cases. In the early papers by Preston-Martin et al. [7,8], a possible increase in the risk of meningioma was found in people exposed to dental X-rays. In other papers the association was found for males exposed to dental X-rays but not for women [9]. Recent epidemiological results on the potential risk from CT-scans in childhood or adolescence suggest an increase of brain tumors risk [10], however, its interpretation is questioned due to the lack of information about the reasons for examination (like suspicion of cancer).

In the case of studies conducted among occupationally exposed nuclear workers or radiologic technologists no significant association between brain tumors and ionizing radiation was found [11–13]. In one study of the effect of radiation on brain tumors from both medical diagnostic and occupational exposure, no association was found between meningioma and ionizing radiation [14] while in the other ones the association was found only for a specific type of tumors like neurinoma but not for glioma or meningioma [15]. In the most recent paper [16], 2-fold increase of risk of brain cancer mortality among radiologic technologists working with fluoroscopy-guided interventional procedures was reported. The authors, however, concluded that the result may be due to chance or unmeasured confounding by non-radiation risk factors.

The brain and neck tumors have been a topic of concern for the community of occupationally exposed interventional cardiologists (ICs) and radiologists (IRs) due to the recent publications reporting the cases of brain and neck cancer among this group [17]. In total, 31 cases were reported in the literature. The mean age of interventional physicians at diagnosis was about 55 years. Glioblastoma multiform was the most common tumor type, detected in 55% of cases, and it was located on the left side of the brain in 85% of cases. It is still not clear whether these malignancies are radiation-induced due to chronical occupational exposure to low doses, or it is a chance occurrence. The association between these tumors and X-ray radiation is explainable by disproportionately higher occurrences of tumors on the left side of the brain, the part of the head known to be the most irradiated one (the X-ray tube and irradiated area are usually on the left side of physician).

The epidemiological study that could answer the above question is difficult to perform mainly because:

- the cancer incidence is expected to be low mainly because the brain is the organ of the lowest radiation sensitivity and the doses are relatively small compared to those used in radiotherapy, and
- if one wants to assess also the lifetime cancer risk, the accurate retrospective evaluation of exposure levels should be done, but this is difficult.

There are also evidences, although still controversial, showing that the low and moderate exposure levels may be associated with elevated risk of non-cancer effects such as cerebrovascular diseases. The International Commission on Radiation Protection, based on the most recent scientific study results, has classified, in Publication 118 [18], the circulatory diseases (among which are cerebrovascular diseases that include stroke, carotid stenosis etc.) as a tissue reaction effect with roughly estimated threshold dose of 0.5 Gy.

In the meantime, an effort should be undertaken to enhance the awareness of physicians concerning the need for optimisation of working technique including the use of dedicated protective means. The latter, in addition to good protective performance, should ensure comfort at work and good ergonomic characteristics to minimise the likelihood of orthopaedic complications [19]. A ceiling-suspended protective screen is the most common radiation protective device that protects the upper parts of physician's body. Its effectiveness in reduction of the eye lens doses and the brain has been also analysed and proven in Monte Carlo simulations and clinical measurements (with respect to eye lens) [20–22]. Lead caps or lead free caps are one of the most recent innovation for protection of the head. They can differ in terms of shape, weight and lead equivalence. Few papers present the results on protective capabilities of lead or lead free caps but their conclusions, due to different methodologies used, are inconsistent [22–27]. Some of them, except one which reports no effect [25], demonstrate its advantage over the ceiling-suspended protective screen, but authors anticipate the effect of lead cap on the head or brain based on the measurements performed on the skin [23–25]. The remaining papers, relying on simulations or measurements performed inside phantom head give consistent conclusions and show rather minimal influence of the lead cap on the doses to the head [22,26,27].

The aim of this study is to provide a deeper insight into the influence of the lead free cap on the dose to the skin, the head and the brain of interventional cardiologists by carrying out measurements in both the clinic during real procedures and laboratory in exposure conditions that mimic the real practice. The latter measurements also allowed to quantify the influence of different projections on the above dose values. Moreover, a rough estimates of an absolute brain dose per procedure, per annum and cumulated during whole career have been given in the paper.

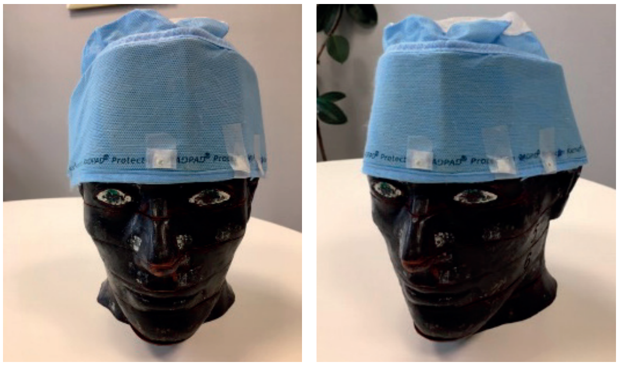
MATERIAL AND METHODS

Clinical measurements

The measurements were performed in 2 dedicated cardiology centres. Three out of 4 cardiologists participating in the study worked in the first center in the same catheterisation lab (thus used similar working technique) while the remaining one worked in the second center. Moreover, in both centers the ceiling suspended lead screen and the table curtain were used routinely. The measurements were performed in 2 phases.

In the first, preliminary one, the measurements were performed per single coronary angiography (CA) and/or CA/percutaneous transluminal coronary angioplasty (CA/PTCA) procedure; only operators from the first center participated in this phase. In total, 30 procedures were performed with the lead free cap with an equivalent of 0.25 mmPb. Six high-sensitivity thermoluminescent dosimeters (TLDs type MCP-N manufactured by Radcard, Poland) were attached at various locations outside the cap: 3 of them on the forehead on the level of eye brows (2 near the left and right temple and 1 in the middle of the forehead), 1 on the top of the head, 1 on the back of the head near the neck and the last at equal distance from the dosimeter at the back and the dosimeter on the top of the head. Three extra TLDs were attached at the corresponding locations on the forehead inside the cap. The measurement protocol included information on the protective measures used, values of dose-area product (DAP), air kerma at the reference point (K_a, r) and fluoroscopy time (FT) as well as the patient characteristics.

In the second phase the doses were cumulated over about 20 procedures, on average, during one measurement, before the dosimeters were read out. This allowed to avoid the problem of bias due to a lower detection limit (LDL) with TLDs when individual CA/PTCA procedures were relatively short. Two physicians, one from each center, were involved in this phase with >70% procedures



The second set of thermoluminescent dosimeters was placed inside the cap in the corresponding positions.

Figure 1. The position of dosimeters outside the lead free cap used in the second phase of the measurements

Figure 2. The geometry of the measuring system in the laboratory

being performed by the physician working in the second center. In total, 14 measurements were performed including doses from 291 procedures. Moreover, only 3 dosimeters outside and inside the lead free cap were attached in the regions of the highest exposure as determined during the first phase: on the left temple, on the left eyebrow and on the forehead between the eyes (Figure 1).

The effectiveness of lead free cap to reduce the doses in various regions on the skin was evaluated from the comparison between the doses measured outside the cap and the corresponding doses measured inside it. The calibration of TLDs was performed in terms of Hp (0.07) quantity on the head phantom employing ISO N-80 reference spectrum [28]. The overall measurement uncertainty is 25% and it is mainly due to energy dependence of TLDs.

The LDL determined with the formula:

$$LDL = 3 \times \sigma \qquad (1)$$

where:

σ – the standard deviation from the readings of background dosimeters, equal to 10 μSv.

Measurement points were excluded from the analysis if in the same location both doses inside and outside the cap were equal or below this limit. In the case when, for a given measurement, one of the doses was below LDL it was replaced with its value.

Laboratory measurements

In order to address the issue of protection to the head and brain provided by the lead free cap additional measurements were performed in the Secondary Standard Laboratory of the Nofer Institute of Occupational Medicine (NIOM). A Philips BV C-arm unit, a Alderson Rando phantom representing the physician and PMMA (polymethyl methacrylate) phantoms representing the patient were used to simulate the typical geometry and exposure conditions (Figure 2). Unlike the clinical conditions the ceiling suspended lead shield was not used in the NIOM laboratory. Four, typically used, projections (PA and LAO 30 [the most frequent ones], LAO 90 [providing the highest exposure to the operator] and RAO 30), were selected to analyse the influence of various exposure geometries on the effectiveness of the lead free cap. The Alderson Rando phantom was set in the distance representative for the position of the physician inserting the catheter into the radial artery (60 cm measured along the treatment table from the X-ray tube to the sagittal plane of the phantom and 45 cm from the mid of the table to the front surface of the phantom). Every time the following exposure parameters were used: 90 kV, 2.9 mA and DAP = 3000 μGy×m^2. The value of the DAP was selected based on the results of clinical measurements in the first and the second phase.

The head of the Alderson Rando phantom was filled with 138 TLD pellets and single exposures were performed with and without the lead free cap for each selected projection (for a given projection one measurement was performed first with the cap and then without) so the absorbed dose in the brain could be assessed. The dosimeters placed in the head of the phantom were calibrated in air kerma (K_a) quantity which for the radiation fields used in interventional radiology is of the similar value; the same as for the skin dose measurements ISO N-80 energy spectrum was used.

As the lead free cap is covering only the upper part of the head the dosimeters in remaining regions were used to evaluate the repeatability of measurements. For the purpose of comparison with the results of clinical measurements, extra dosimeters were placed on the lead free cap, inside and outside it, in 2 positions corresponding to the ones used during procedures performed in the catheter lab with interventional cardiologists (1 near the left temple and 1 in the middle of the forehead).

The dose reduction factor (RF) of the lead free cap for the brain and for a given projection was estimated as a quotient of the average absorbed dose from all dosimeters placed inside the brain (including cerebellum; slices 1–5) of the phantom without the lead free cap to the average absorbed dose calculated for the dosimeters from the same region when the lead free cap was on the phantom's head. The same rule was used to evaluate the RF for the head, however, in this case all dosimeters inserted into the head (slices 1–8) were taken into account.

Moreover, the measurements performed with the Alderson Rando phantom in the laboratory allowed to estimate roughly the brain dose the operator receives during a single procedure, annually (annual brain dose) and during the whole working career (life brain dose) as well as the corresponding doses when the lead free cap is used. For this purpose, the following assumptions were made concerning the typical CA/PTCA procedure: DAP value for individual procedure equals to 3000 μGy × m^2, 30% contribution of PA, LAO 30 and RAO 30 projections in the DAP and 10% contribution of LAO 90 and finally an annual workload and years of work in exposure during professional career of the interventional cardiologist – 550 procedures performed [29] and 25 years, respectively. The annual dose to brain when the lead free cap is used was assessed using the same assumptions and the average value of RF obtained from the phantom study.

Statistical analysis

Differences between 2 types of doses (measured outside and inside the lead free cap or measured inside the head with and without the lead free cap) were assessed using Student's t-test or Mann-Whitney U test depending on the character of data distribution (normal or non-normal). A p-value < 0.05 was considered significant.

RESULTS

Clinical measurements

The characteristics of exposure conditions including DAP, CD, FT and DAP normalized doses measured outside the cap on the left temple and middle forehead collected during CA/PTCA procedures are presented in Table 1. The data represent the mean values per single measurement for each exposure parameter. In the first phase of measurements, for >63% of procedures the doses measured inside or/and outside the lead free cap, were below LDL; on the right temple for 17 out of 30 procedures both doses, measured inside and outside the protection, were below LDL while on the middle forehead for 2 procedures and only inside the cap were below LDL. In the second phase, the doses were above LDL for all measurements. Figure 3 presents the mean skin doses per measurement (that is per procedure for the measurements performed in the first phase or per cumulated procedures in the second phase) calculated for various positions inside and outside the lead free cap. On the left temple and

Table 1. Exposure characteristics (DAP, CD and FT) concerning procedures performed in the first and second phase of measurements and the input doses for interventional cardiologists measured on the head outside the lead free cap in clinic (2017–2019)

Variable	Measurements phase					
	first*			second**		
	M±SD	Me	range	M±SD	Me	range
DAP [$\mu Gy \times m^2$]	2193±1877	1795	109–8817	27 219±13 191	25 898	10 468–51 562
CD [mGy]	563±484	397	106–2176	5830±2999	6271	1875–11 844
FT [min]	4.2±3.3	3.3	1.1–14.2	110±72.9	82.2	17.8–291.7
Hp(0.07) [mSv]						
left temple outside	0.05±0.03	0.04	0.02–0.14	0.18±0.11	0.14	0.05–0.41
middle forehead outside	0.04±0.03	0.04	0.01–0.14	0.12±0.10	0.09	0.03–0.34
Hp(0.07)/DAP [$mSv/\mu Gy \times m^2$]						
left temple outside	4.2E-5±4.4E-5	2.9E-05	8.6E-06–2.2E-04	3.3E-6±2.1E-6	2.2E-06	1.5E-06–7.7E-06
middle forehead outside	3.6E-5±3.7E-5	2.1E-05	6.3E-06–1.5E-04	2.4E-6±2.0E-6	1.5E-06	7.3E-07–7.6E-06

CD – cumulative dose; DAP – dose-area product; FT – fluoroscopy time.
* The measurement per procedure.
** The measurement includes doses (or fluoroscopy time) from many procedures (on average 20 procedures).

in the middle of the forehead about 3 times higher doses were cumulated outside the cap during the second phase. The differences between doses measured inside and outside the cap on the forehead and temple were statistically significant for both phases. The doses measured in the parts of the head not protected by the lead insert (top, back or in the region between both) are comparable and low, close to the LDL (Figure 3a).

Table 2 shows mean values, median values and the ranges of the reduction factors. They were calculated for the given dosimeter position as the mean or median value of quotients of the dose measured outside the cap to the dose measured inside it for each procedure.

The ranges of reduction factors obtained in measurements performed during single procedures vary from 1.0 up to 3.8 while for measurements cumulated during many procedures from 1.1 up to 4.0 (Table 2). The average reduction factors across the forehead for given measurement phase range from 1.6 for the right temple up to 1.8 for the left temple for the first phase and from 2.0 up to 2.3 for the second one (the standard deviation for reduction factors measured in a certain position on the forehead is 0.1). The average RF calculated for all measurements from both first and second phase are 1.9 and 1.8 on the left temple and in the middle of the forehead, respectively.

Laboratory measurements

Effect for the skin

Laboratory measurements show that the dose RF for the skin of the head changes depending on the projection and position of the dosimeter (Table 3). For the dosimeters placed on the left temple and in the middle of the forehead, the highest dose RF (the quotient of the dose measured on the lead free cap to the dose measured inside this cap) is observed for the left temple. Its value ranges from 6.3 up to 8.7 depending on the projection and is the highest for RAO 30 (RF = 8.7) and lateral one (RF = 7.8) and comparable for both PA and LAO 30 (6.6 and 6.3, respectively). In the middle of the forehead the values of RF are in general lower than for the left temple and range from 1 for LAO 90 up to 4.8 for LAO 30, 3.3 for RAO 30 and 2.8 for PA.

Effect for the head and the brain

Some reduction in the dose for the head was observed only in 2 consecutive slices (counting from the top of the head: slice no 1 and 2 in Alderson Rando phantom) that were wrapped by the lead free insert of the cap (Table 3). Due to the fact that for the clinical settings the incident radiation comes from the left side of the operator, only the left part of his head directly covered by the lead free insert is protected. The level of protection, when one restricts the analysis to the area of the slices covered by the lead free insert only, varies depending on the projection and is the highest for LAO 90 (RF = 1.8) and declines with decreasing of the angle: 1.6 for LAO 30 and 1.4 for PA projection while for RAO 30 projection its value is the same as for PA. When RFs are calculated for the whole brain (the slices No. 1–5 in Alderson Rando phantom) and not only the part covered by the lead free cap, they become much lower: 1.1, 1.1, 1.0, and 1.0 for LAO 90, LAO 30, PA, and RAO 30, respectively because only small part of the brain is protected. The same concerns the head for which the following reduction factors were obtained 1.1, 1.1, 1.0, and 1.1, respectively with the averaged, over all projections, RF equal to 1.1.

Estimation of brain dose per procedure as well as brain annual and life dose

The estimated brain dose per typical CA/PTCA procedure (total DAP about 3000 $\mu Gy \times m^2$, the respective use of PA, LAO 30, RAO 30, and LAO 90: 30%, 30%, 30%, and 10%) is 13 μGy while the annual (for 550 procedures performed yearly [28]) and life brain dose (for 25 years of practice) are about 7.2 mGy and 180 mGy, respectively. It can be further assessed (taking the weighted average for the reduction factor of 1.08) that the brain cumulative dose will be reduced by about 15 mGy if the protective cap is always used by the operator during his/her whole working career.

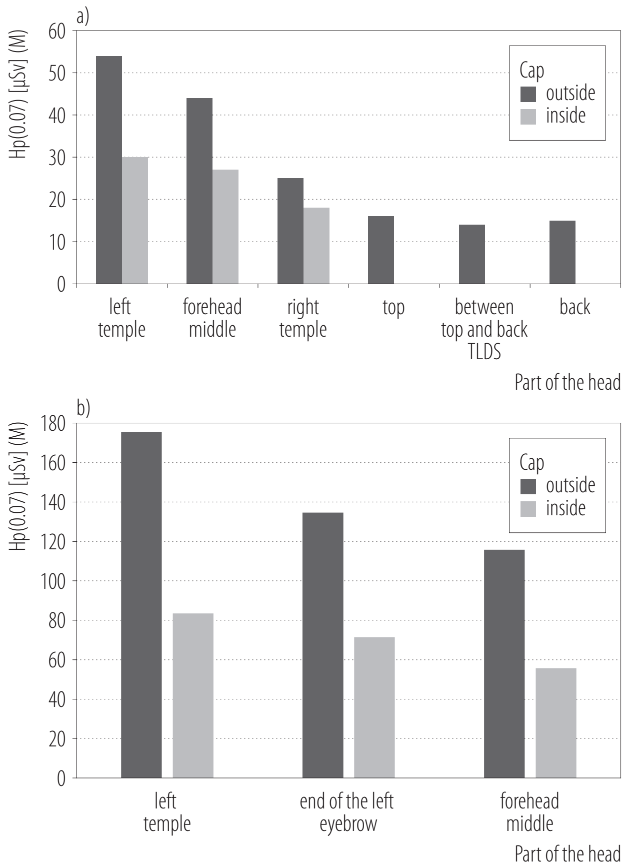


Figure 3. Skin doses per measurement in various places on the head of interventional cardiologists outside and inside the non-lead cap assessed based on the results from a) the first phase and b) the second phase of clinical measurements (2017–2019)

DISCUSSION

Based on the measurements performed during individual procedures (first phase) it can be observed that the mean exposure to the operators' left forehead without an additional head protection is on the similar level to the one reported in ORAMED (Optimisation of Radiation Protection for Medical Staff) survey (54 μSv in this study compared to 52 μSv in ORAMED survey [30]). The differences in determined RFs for the first and the second phase of clinical measurements might be ascribed to differences in:

– monitored procedures in particular in exposure parameters such as tube voltages used (caused by dif-

Table 2. Comparison of reduction factors calculated first from doses measured on the head of interventional cardiologists per procedure and then from doses cumulated from many procedures in clinic (2017–2019)

Reduction factor	Measurements phase								
	first*			second**			first and second		
	M	Me	range	M	Me	range	M	Me	range
Left temple	1.8	1.7	1.0–2.9	2.3	2.5	1.5–3.3	1.9	1.8	1.0–3.3
Right temple	1.6	1.4	1.1–3.0	–	–	–	–	–	–
Forehead middle	1.8	1.6	1.1–3.8	2.0	2.0	1.5–3.0	1.8	1.7	1.1–3.8
End of left eyebrow	–	–	–	2.1	2.0	1.1–4.0	–	–	–

* The measurement per procedure.

** The measurement includes doses (or fluoroscopy time) from many procedures (on average 20 procedures).

Table 3. Dose reduction factors for the skin, brain and head for given projection – data from the measurements performed on the Alderson Rando phantom in laboratory (2019–2020)

TLD position and anatomical region	Dose reduction factor			
	PA	LAO 30	LAO 90	RAO 30
Skin				
in between eyes	2.7	4.8	0.9	3.3
left eyebrow	5.0	6.1	4.1	6.7
left temple	6.6	6.3	7.8	8.7
Slice				
1–2: part of the head covered by the cap	1.4	1.6	1.8	1.4
1–5: brain with cerebellum	1.0	1.1	1.1	1.0
1–8: head	1.0	1.1	1.1	1.1

LAO – left anterior oblique; PA – posterior anterior; RAO – right anterior oblique; TLD – thermoluminescence dosimeter.

ferent settings of AEC systems of C-arm units used in both centres, patient's BMI etc.);
– working technique (different projections used and distance from the X-ray source to physician);

or they might be by chance.

These differences are evidenced in the values of doses normalized to DAP (Hp(0.07)/DAP) outside the cover for first and second phase which are presented in table 1. Moreover, the effect of statistical bias related to LDL can not be excluded. In fact, in the second phase all dose values were above LDL (in majority of cases well above) thus the effect of LDL on the obtained reduction factors might be neglected while in the first phase it can not be – some doses were below LDL and the remaining above but still close to LDL as measurements were performed per procedure.

According to the results of clinical measurements presented above the dose values measured on the skin can be reduced 2.3-fold on the left temple when the lead free cap is used by the operator. In other considered positions, the effectiveness of the lead free cap is comparable (the corresponding RFs are around 2.0 for both the "middle forehead" and "end of the left eyebrow"). The same or lower value is estimated for the right temple on the basis of the results from the first phase of measurements.

The observed differences in the RFs calculated based on the measurements performed in the laboratory and in clinical conditions result primarily from the fact that the former measurements performed under static conditions on the phantoms (for given kVp and distance and for few selected projections) are some simplification of realistic situation and do not reproduce the great variety of settings. They also do not include the presence of ceiling suspended lead screen used routinely during clinical measurements. Indeed, for the left temple the reduction factors obtained in laboratory conditions for all considered projections range from 6.6 up to 8.7 while in clinics, in the best case, they reach at most 4.0. These differences could be partly explained by the fact that during real procedures different energies of radiation or various types of projections and distances of physician to the X-ray source were used. However, the contribution of these factors, based on the results of this study and results of Monte Carlo simulations [31], is rather small and not enough to explain much lower effectiveness of the lead free cap in clinical practice (the reduction factor on average 2.3). This fact might indicate that an important factor is a good fitting of the cap to the size of the head and that its adherence to the skin matters for radiation protection.

Measurements performed in laboratory gave an insight in the distribution of the dose inside the head and its attenuation by the lead free cap. Generally, the reduction factors for LA0 90 for which the X-ray tube is the nearest to the left side of the physician is the highest because the area "seen" by the scattered from the patient radiation is greatest and hence the probability that radiation will pass through the insert is the largest one for this projection. However, taking into account that 25% uncertainty is expected, there is no measureable difference between doses to the head and the brain for any projection. This is for 2 reasons: firstly the cap covers the head only partially (also the scattered in the head radiation might come in through unshielded parts) and secondly the effectiveness of the shield varies with projection type and depends on the work technique. The results obtained in this study are quantitatively consistent with the results obtained by Honorio da Silva et al. [22], where a dose reduction to brain of 6% after the use of a surgical lead cap was demonstrated.

Of all dosimeters placed in the phantom head and for all analysed projections (PA, LAO 30, LAO 90, and RAO 30) the highest dose was recorded by a dosimeter placed close to the left temple when head was not covered by lead free cap. However, the level of exposure differs significantly depending on projection type. Even 3.6 times higher doses are observed for LAO 90 compared to RAO 30 for which the doses are the lowest (in this projection the distance of the X-ray tube from the physician's head is the largest).

The dosimeters with the highest doses were, however, not covered or only part of them was covered (for LAO 90 projection) by the lead free cap, therefore, it has not influenced the maximum doses or influenced them slightly (maximally 11% reduction in doses is observed for LAO 90).

According to physicians participating in the study the level of comfort has not decreased due to the use of the lead free cap while performing the procedures.

The brain dose of 13 μGy estimated for the physician performing CA/PTCA procedure is consistent with the doses reported in the paper by Ferrari et al. [32] in which Monte Carlo simulations with anthropomorphic phantoms were used. Indeed, for the DAP values range, between 20 $Gy \times cm^2$ and 40 $Gy \times cm^2$ (thus containing the value used to estimate brain dose in the present study) and for the same conditions i.e., no shielding protecting the brain used (such as ceiling or lateral shielding, lead or lead free cap) the estimated in the quoted paper absorbed dose in the brain ranged 12–24 μGy per procedure. Based on the recent results of the study analysing the risk of NST in Life Span Study (LSS) cohort of atomic bomb survivors [2], where the ERR/Sv for tumors of any type due to ionizing radiation was estimated to be 1.4/Sv, the cumulative risk of brain tumor (at the end of the working career) is about 25% higher than the baseline risk. According to the presented results, the risk can be further reduced by 2% when the lead free cap is used. The above estimate needs to be treated with great caution as both the type and exposure levels of radiation as well as the fractionation are different than in the LSS cohort. One has also to keep in mind that NST are the tumors developed in brain but also in spine cord which, in case of interventional cardiologists, in its major part is protected with lead apron and thyroid collar.

Furthermore, regarding for instance non – cancer effects, the 0.18 Gy cumulated life dose for brain assessed in the present study is lower than the new, threshold dose for cerebrovascular diseases of 0.5 Gy as recommended by ICRP in Publication 118 [18]. On the other hand, one has to keep in mind that the uncertainty in determining the risk of cerebrovascular diseases in low and moderate radiation dose levels is considerable and, therefore, it is also the case for the threshold dose. The same concerns the estimation of brain doses in the present study which was based on simplified assumptions.

Due to above mentioned ambiguities, the importance of optimisation of working practice in interventional cardiology labs should be emphasised, including the use of various radiation protection shields which effectiveness in protection of the head have been proven and for which the potential benefits of their use outweigh their costs. With regard to the first issue which is within the scope of this study, taking into account both the assessed effectiveness of the lead free cap and the evaluated risk of NST by Brenner et al. [2] it seems that the analysed radiation protection cover has the potential to only slightly reduce the cumulated brain dose and the cumulative risk of brain tumor and that is only in the situation it would be worn by interventional cardiologists during their entire clinical practice.

CONCLUSIONS

The effectiveness of lead free cap in protection of the brain is very limited (the average doses reduction factor is 1.08) compared to protection it provides for the skin of the forehead (2.3-fold reduction in clinical practice). These conclusions also indicate that the dose measured on the skin near left temple is not good approximation of the brain dose.

The estimated brain dose per procedure in the case when no protection is used is 13 μGy. The use of the lead free cap allows to reduce it by about 8% which, if the protection is worn during each procedure, would lead to reduction in annual dose of approximately 0.6 mGy.

Moreover, the analysis of dose distribution shows that from all dosimeters inserted in the Alderson Rando head the dosimeter which registered the highest dose was located on the left temple for all projection types analysed in the study.

Some benefits consisting of reduction of the exposure to operator's skin seem to be considerable unless one takes into account that the typical dose on the skin of the head is still far below the annual limit for the skin (500 mSv). Regarding the protection of the brain the effectiveness of lead free cap is relatively low. Moreover, the long term side effects for the skeletal system due to the routine use of this protection are not recognised yet. Therefore, as for today, the emphasis should be placed on the regular use of accessible in most catheter labs shields which effectiveness was already proven (such as the ceiling suspended lead screen) wherever it is possible.

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