Radiography 27 (2021) 255–259

Contents lists available at ScienceDirect

Radiography

journal homepage: www.elsevier.com/locate/radi

Measurement of the average radiation dose to the local skin and thyroid gland during intracranial aneurysm coil embolization

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ARTICLE INFO

Article history:
Received 8 April 2020
Received in revised form
27 July 2020
Accepted 29 July 2020
Available online 15 August 2020

Keywords:
Air-kerma area product
Diagnostic reference level
Intracranial aneurysm coil embolisation
Radiation dose measurement
Thermo-luminescent dosimeter

ABSTRACT

Introduction: Intracranial aneurysm coil embolisation is a fluoroscopically guided procedure associated with high radiation dose. The increase in the number of coil embolisation procedures raises concern for the amount of radiation and the associated radiation risks to the patients. This research study was conducted to determine the average radiation dose to patients' thyroid glands and local skin during intracranial aneurysm coil embolisation and to establish preliminary local diagnostic reference levels for this procedure. In this paper, local skin dose refers to the absorbed radiation dose on the areas of the skin exposed to radiation during intracranial aneurysm coil embolisation, namely neck, face and scalp.

Methods: This study employed air-kerma area product meters to determine the local skin dose and diagnostic reference levels during intracranial aneurysm coil embolisation. In addition, thyroid radiation doses were measured using thermo-luminescent dosimeters on a phantom during simulation of embolisation procedures.

Results: The local skin doses as determined by air-kerma area product ranged between 33 and 125 Gy.cm2. The mean thyroid dose was 9.87 mGy. The established local diagnostic reference level was 52.1 Gy cm^2, 17.8 min' fluoroscopy time and 503 image frames.

Conclusion: The average air-kerma area product values and the proposed diagnostic reference levels were lower than most published values for intracranial aneurysm coil embolisation.

Implications for practice: The established local diagnostic reference levels are recommended for use as radiation dose optimisation tool at the research site. The findings of this study cannot be generalised or applied to other hospitals. The complexity of the embolisation procedures was not classified for this study. Further research on diagnostic reference levels for intracranial aneurysm coil embolisation, taking into account the complexity of the procedures, is recommended.

Introduction

Ruptured intracranial aneurysms are a leading cause of subarachnoid haemorrhage (SAH) accounting for about 75% of all cases[1,2] and have a mortality rate of 45%.[3] Intracranial aneurysms can be treated by endovascular coil embolisation or surgical clipping. The International Subarachnoid Aneurysm Trial (ISAT) recommended endovascular coil embolisation, which has led to an increase in the number of endovascular embolisation procedures worldwide.[4] Endovascular coil embolisation is a fluoroscopically guided interventional procedure associated with high radiation dose. The increase in the number of endovascular embolisation procedures raised concerns about the radiation risks to the patients.[5]

The eyes, the brain and the thyroid gland are most likely to be affected by radiation during intracranial aneurysm coil embolisation due to the radiosensitivity and close proximity of these organs to the radiation beam during intracranial aneurysm coil embolisation. The skin on the face, neck and the scalp is also exposed to radiation during intracranial aneurysm coil embolisation.[5,6] The other organs that are exposed to radiation during intracranial aneurysm embolisation are the oral mucosa and salivary glands, however due to their low radiosensitivity (tissue weighting factor = 0.01) they are less likely to be affected by radiation.[7]

This study was conducted to determine the radiation doses to the thyroid gland and local skin (face, neck and scalp) during

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https://doi.org/10.1016/j.radi.2020.07.019
1078-8174/

intracranial aneurysm coil embolisation and to establish preliminary local diagnostic reference levels (DRLs) for intracranial aneurysm coil embolisation at a tertiary academic hospital.

Literature review

Exposure to radiation can result in stochastic and deterministic effects. Stochastic effects of radiation are most likely to occur in diagnostic radiology; however deterministic effects can also occur following complex fluoroscopically guided procedures where threshold doses can be exceeded.[8]

Peak skin dose (PSD) is the preferred dose metric to estimate the deterministic risk to the patients. However, PSD is difficult to measure, especially for interventional procedures with multiple fluoroscopic and radiographic projections.[9] Correctly positioned thermo-luminescent dosimeters (TLDs) can give an accurate estimation of PSD.[10] It is, however, often impossible to know the area of highest skin dose beforehand in procedures involving various projections. In addition, TLDs do not provide real-time dose display. The radiation dose information is only available after the procedure once the TLDs have been read.[10–12] Radiochromic films also provide a good estimation of entrance skin dose, however, like TLDs, there is no real time dose display.[13] In the absence of peak skin dose information, air-kerma area product (KAP) is recommended for estimating local skin dose. While KAP does not provide an accurate indication of the deterministic risk, it gives a good estimation of the total X-ray energy absorbed by the patient.[9] In addition, a good correlation between PSD and KAP for neuro-interventional procedures has been reported.[12–14]

Previous studies found that the threshold dose for early transient erythema (2 Gray) and temporary epilation (3 Gray) can be exceeded during neuro-embolisation procedures.[14–17] Doses higher than the brain threshold dose of 500 mGy for cerebrovascular disease have also been reported.[18,19] Some studies recorded KAP values from neuro-embolisation procedures. The maximum KAP values from these studies were 1143 Gy cm^2,[13] 436 Gy cm^2[14] and 366 Gy cm^2.[20] Patient follow-up for possible skin injuries is recommended following exposure to KAP values greater than 500 Gy.cm2[9] while a threshold dose of 700 Gy cm^2 was suggested for early transient erythema.[13]

The thyroid gland is also exposed to radiation (mainly scatter radiation) during intracranial aneurysm coil embolisation. Radiation exposure to the thyroid gland is associated with thyroid cancer induction, especially in children.[5] A positive association between thyroid radiation dose and thyroid cancer in women has been reported.[21] Other effects of radiation on the thyroid gland, in adults, are hypothyroidism, hyperthyroidism and benign thyroid nodules.[19,22] Mean thyroid doses of 6.3 mGy, 8.29 mGy and 24 mGy from cerebral embolisation procedures have been previously reported.[5,23,24]

To minimise the harmful effects of radiation, adherence to radiation protection measures during fluoroscopically guided procedures is necessary. Radiation protection in medical exposure is underpinned by the principles of justification and optimisation of exposure. Justification requires that radiation exposure is performed when there is sufficient benefit to the patient while optimisation entails ensuring that, for justified procedures, the radiation exposure is optimised so as to maximise the benefit to the patients while minimising the radiation risks.[7] One of the methods of applying the optimisation principle is the use of DRLs. The concept of DRLs was introduced by the International Commission on Radiological Protection (ICRP) in 1996 as a dose management tool against which patient doses are compared to identify abnormal levels of radiation. DRLs should be set at local, regional and national level for all common diagnostic examinations as well as all procedures that produce high radiation doses.[25]

Patients' size has an effect on the radiation dose, therefore DRLs are set at the 75th percentile of the radiation doses to standard sized patients, weighing around 70 kg. For local DRLs the median value of the radiation doses is recommended due to the limited sample size. The radiation dose parameter used for setting a DRL depends on the type of examination. For fluoroscopic procedures, the parameter used is the KAP. The number of acquired images or frames, fluoroscopy time and cumulative dose, if available, must be included when setting DRLs for interventional procedures. Including these parameters would make it easy to identify the reasons for high radiation doses, should they occur.[25,26]

Methods

The study design consisted of two components. The first component involved a quantitative, prospective study where air-kerma area product meters were used to determine the local skin doses over the neck, face and scalp as well as diagnostic reference levels during actual embolisation procedures on patients. The second component entailed measurement of the radiation dose to the thyroid gland on a phantom during simulation of intracranial aneurysm coil embolisation procedures, here after referred to as the phantom based simulation studies.

The principles of the Declaration of Helsinki were upheld during this study.[27] Patients who were scheduled for intracranial aneurysm coil embolisation between January 2018 and November 2018 were recruited for participation. Patients with low levels of consciousness and children were excluded from the study. A total sample size of 30 adults of all genders was enrolled for the actual coil embolisation component of this study. Written informed consent was obtained from all research subjects. Ethics approval for this research study was granted by the two research ethics committees associated with the research site.

All studies were performed using a Siemens Artis Zee biplane angiography unit (2014 model) manufactured in Germany. Both X-ray tubes were fitted with permanent KAP meters. The KAP meters were calibrated by the service engineer according to the manufacturer's specification as part of the annual equipment quality control. The previous KAP meter calibration was performed in December 2017, therefore the KAP meter was not calibrated for the purposes of this research.

Patients with suspected intracranial aneurysms underwent uncontrasted computed tomography of the brain (CTB) as well as computed tomography angiography (CTA) of the brain to confirm the presence of intracranial aneurysms. This allowed for only the intracranial artery with the aneurysm to be cannulated and imaged during intracranial aneurysm coil embolisation resulting in possible reduction in radiation exposure. The actual coil embolisation procedures were performed by a neuro-interventional fellow under direct supervision of one of the experienced neuro-interventionists. Procedures that were deemed challenging were performed by one of the experienced neuro-interventionists. The complexity of the procedure was not actively explored during this study.

During the embolisation procedures, the Seldinger technique was used to introduce the catheter via the femoral artery.[28] A low dose neuro-radiology program with Combined Applications to Reduce Exposure (CARE) was used for all embolisation procedures. The fluoroscopy frame rate was 10 pulses per second and the angiographic acquisition frame rate was 4 frames per second. The intracranial artery of interest was selected in each patient and angiographic images were acquired in postero-anterior and lateral projections. A three dimensional rotational angiogram with 133 frames over 200°' rotation was performed when necessary to view the aneurysm in three dimensions. Following these initial angiographic images, the view that best demonstrated the aneurysm (here after referred to as 'the working view') was identified and the magnified images (16 cm or 11 cm) in that particular view, were performed. A roadmap in the working view projection was used for micro-catheterisation and coil deployment in the aneurysm. Where possible, the radiation beam was collimated to the required field of view to reduce scatter radiation. KAP, fluoroscopy time and number of image frames were documented. KAP was used to estimate local skin dose while KAP, fluoroscopy time and number of image frames were used to determine local DRLs. Subjects' weight was not considered in view of the findings of a study by Miller et al. that showed no difference in DRLs between a group where patients' body weight was considered and the group where the weight was not considered.[29]

The phantom based simulation studies were performed for thyroid radiation dose measurements as it was not possible to perform direct thyroid measurements on research subjects. Lithium fluoride doped in magnesium and titanium (LiF:Mg,Ti) TLD chips were used for radiation dose measurements. TLDs have to be calibrated before use to determine their response to a certain energy level and to improve their accuracy.[30] The TLDs used for this study were calibrated against a PTW – Freiburg 30 cm^3 cylindrical ionization chamber using the calibration method recommended by the International Atomic Energy Agency (IAEA).[30] One TLD was not exposed to radiation; it was left behind the control panel to measure background dose which was subsequently subtracted from the TLD readings. A male upper body Alderson's RANDO phantom with natural human skeleton and a material that is equivalent to human soft tissue was used. This phantom has transverse slices with removable parts[26] which enabled the placement of the TLDs directly at the anatomical thyroid gland location. During each simulation, four TLDs were placed on the phantom to measure the radiation dose. Two TLDs were placed on the anterior neck, over the thyroid region, while the other two were placed in the thyroid gland hole, on the cranial end of slice ten of the phantom. This TLD position is similar to that used in a study by Acun et al. for thyroid gland dose measurements on a phantom.[31]

The phantom based simulation studies were carried out after all data were collected during the actual coil embolisation studies. Procedures that recorded the shortest, medium and longest fluoroscopy time during the actual coil embolisation studies were simulated. The parameters that were used for each of the aforementioned procedures (listed in Table 1) were extracted from Picture Archiving and Communication System (PACS) and replicated. To ensure reliability of results, the simulation of each scenario was repeated three times.

Results

This study included 30 research subjects who had intracranial aneurysm coil embolisation procedures during the study period. Seventeen of these procedures were performed by a neuro-interventional fellow while thirteen were performed by experienced neuro-interventionists. The KAP values recorded during this study ranged from 33.0 Gy cm^2 to 125.7 Gy cm^2 with a mean of 56.1 Gy cm^2. The mean KAP from the procedures performed by the fellow and those performed by the experienced neuro-interventionist were 43.1 Gy cm^2 and 73.6 Gy cm^2 respectively.

The thyroid doses recorded during the phantom based simulation studies ranged from 4 mGy to 13 mGy with a mean of 9.87 mGy (Table 2). TLD readings for the third simulation of scenario 1 were considerably higher than the readings from the other two simulations of the same scenario; 13 mGy vs 5 mGy for thyroid doses. These high TLD readings were considered inaccurate, presumably due to errors in the TLD reading process and were therefore discarded. The decision to exclude these high readings was done in accordance with a study by Rybicki et al.[32] where high TLD readings were also excluded.

The results of the phantom based simulation studies also showed that the thyroid gland readings were higher than the anterior neck readings for all simulations (Fig. 1). This was contributed to the fact that there was more attenuation of the X-ray beam before reaching the anterior neck as the images were acquired in postero-anterior projection. This is an important finding relevant for future research studies involving estimation of the radiation dose to the thyroid gland on human subjects.

The mean thyroid doses obtained during this study are compared to those reported in previous studies in Table 3.

The median values of KAP, fluoroscopy time and number of image frames were used to determine local DRLs. The proposed local DRL from this study was 52.1 Gy cm^2, 17.8 min' fluoroscopy time and 503 image frames. These values are compared to DRLs from published studies in Table 4.

Discussion

The KAP was used to estimate local skin dose during this study. Previous studies reported a good correlation between KAP and PSD.[12–14,24] A study conducted to determine maximum skin dose in cerebral embolisation procedures suggested a KAP of 700 Gy cm^2 as the threshold dose for early transient erythema.[13] Patient follow-up for possible skin injuries is recommended for patients exposed to KAP values greater than 500 Gy cm^2.[9] The KAP values recorded

Table 2
Mean thyroid gland doses recorded from the phantom based simulation studies.

Scenario	Mean thyroid dose (mGy)
1	5.0
	4.0
2	10.5
	11.5
	11.5
3	11.5
	12.0
	13.0

Table 1
Imaging parameters used for three simulated scenarios during phantom based simulation studies.

Imaging parameter	Scenario 1 (shortest fluoroscopy time)	Scenario 2 (medium fluoroscopy time)	Scenario 3 (longest fluoroscopy time)
Fluoroscopy time (minutes)	4.9	22	41.1
KAP (Gy·cm^2)	36.6	33	77.8
No. of exposures	12	10	22
No. of image frames	368	372	534
Working view	LA0 90°	LAO 130°cranial 30°	RA0 30° caudal 45°

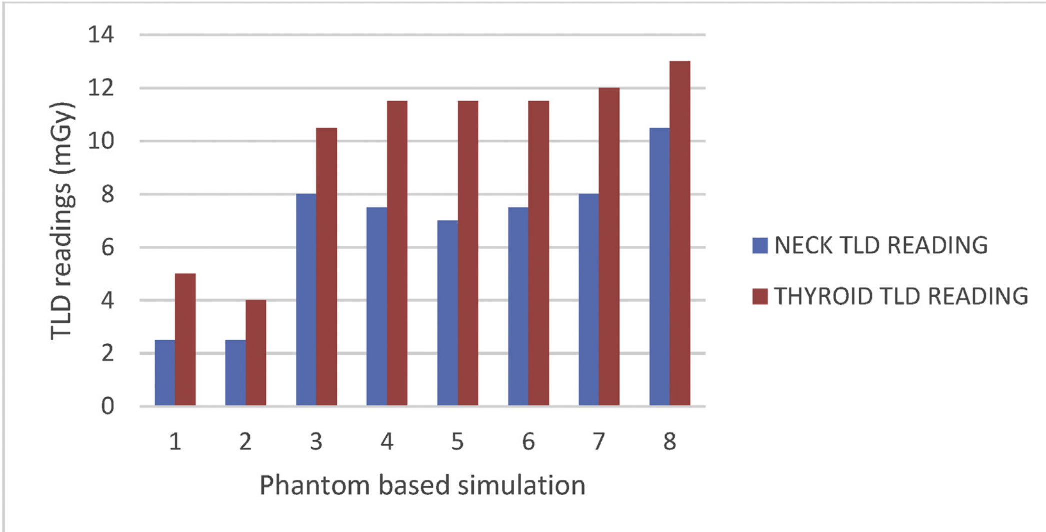

Figure 1. Comparison of neck TLD readings with thyroid gland TLD readings during phantom based simulation studies.

Table 3
Comparison of mean thyroid doses from this study with the thyroid doses from published studies.

Study	Mean thyroid doses (mGy/mSv)
Shortt et al., 2007[5]	8.29
Theodorakou & Horrocks, 2003[24]	24.00
Lunelli et al., 2013[23]	6.30
This study	9.87

during this study were well below these aforementioned values. Therefore, it is unlikely that radiation-induced skin injuries could occur in patients following intracranial aneurysm coil embolisation at the research site.

The thyroid doses recorded in this study were below the 50 mGy–100 mGy dose range linked to thyroid cancer induction,[22] suggesting that patients exposed to radiation during intracranial aneurysm coil embolisation at the research site, were at a reduced risk of developing radiation-induced thyroid cancer.

Diagnostic reference levels for adults are usually defined for an average-sized person.[26] The patients' weight was however not considered in this study because Miller and colleagues found that the patient's weight did not influence the radiation dose to patients during cerebral angiography.[29] The complexity of the procedure should also be factored in when setting DRLs for fluoroscopy guided procedures as it affects the radiation dose, however, this requires large amounts of data.[25] The complexity of the embolisation procedure was not considered for this study as the sample size was not large enough.

A wide variation in the DRLs for intracranial embolisation was evident. This variation could be attributable to a number of factors including experience of the interventionists, equipment age, different dose reduction technologies on equipment, and imaging techniques and protocols employed at different hospitals. Complex embolisation procedures can result in an increased radiation dose as prolonged fluoroscopy may be required to deploy the catheter and coils successfully in the aneurysm. Complex aneurysms also warrant additional image acquisitions to clearly define the aneurysm and its neck.[20]

This study recorded low doses presumably due to the dose optimisation techniques employed at the research site, and the dose reduction technologies incorporated in the angiography unit that was used. A low dose neuro-radiology program with Combined Applications to Reduce Exposure (CARE) was used for all procedures. The low dose mode can reduce the radiation dose by up to 5 times compared to normal dose mode.[42] The procedures were performed by a neuro-interventional fellow under the direct supervision of one of the two experienced neuro-interventionists with approximately 15 years of experience. The procedures that were considered as challenging were performed by one of the

Table 4
Comparison of DRLs from this study with DRLs from published studies.

Author/Year of publication	Country	Sample size	Fluoroscopy time (min.) (3rd quartile)	No. of image frames (3rd quartile)	DRL (Gy.cm^2) (3rd quartile)
Verdun et al., 2005[33]	Switzerland	58	Not available	Not available	352.0
Bor et al., 2005[34]	Turkey		5.3–140	526 - 1912 (range)	215.7
Aroua et al., 2007[35]	Switzerland	58	3.3–134.0 (range)	60.0–3348.0 (range)	440.0
Miller et al., 2009[29]	United States of America	148	90.0	1350	339.4
Sandborg et al., 2010[14]	Sweden	226	7–189 (range)	Not available	157.0
D'Ercole et al., 2012[36]	Italy	72	46.1	664.8	486.1
Söderman et al., 2013[37]	Sweden	38	16.0	845	196.0
Erskine et al., 2014[38]	Australia	91	32.0	Not available	152.9
Chun et al., 2014[39]	Korea	111	61.0	241 ± 92 (mean)	272.8
Ihn et al., 2016[40]	Korea	371	64.7	567.3	271.0
Etard et al., 2017[41]	France	427	58	1080	186.5
This study	South Africa	30	17.8 (median)	503.0 (median)	52.1 (median)

experienced neuro-interventionists. This might have also contributed to the low doses reported in this study.

Conclusion

This study investigated radiation doses to patients' skin using KAP meters while the thyroid absorbed doses were measured on a phantom using TLDs. Local DRLs for intracranial aneurysm coil embolisation at the research site were also established.

The radiation doses recorded during this study are lower than those reported in most published studies for similar procedures. These low doses imply that patients who undergo intracranial aneurysm coil embolisation at the research site are not at risk of developing deterministic effects of radiation.

Conflicts of interest statement

None

Acknowledgements

The authors would like to thank Mr Vuyisile Jonas (MSc: Medical physics) for his assistance with calibration, reading and annealing of thermo-luminescent dosimeters used for this study and Ms Cherral Bourne (Chief radiographer at the research site) for her assistance during data collection.

Funding for this study was received from the Cape Peninsula University of Technology University Research Fund.

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