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Association of radiation-induced epilation and interventional neuroradiology procedures

Deborah Carrick,[1] Vinicius Carraro do Nascimento,[2] Laetitia de Villiers[2] and Henry Rice[2]

1 Biomedical Technology Services, Gold Coast University Hospital, Southport, Queensland, Australia
2 Department of Interventional Neuroradiology, Gold Coast University Hospital, Southport, Queensland, Australia

D Carrick BSc, MSc; **VC do Nascimento** MD, FRANZCR, CCINR; **L de Villiers**; **H Rice**.

Correspondence
Mrs Deborah Carrick, Biomedical Technology Services, Gold Coast University Hospital, 1 Hospital Boulevard, Southport, Qld 4215, Australia.
Email: deborah.carrick@health.qld.gov.au

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Abstract

Introduction: The aim of this study is to quantify the association of temporary epilation following interventional neuroradiology (INR) procedures and compare the peak skin dose ($D_{skin,max}$) threshold to published values.
Methods: Gold Coast University Hospital (GCUH) is a major centre for INR with over 500 primarily interventional procedures performed every year. $D_{skin,max}$ is calculated when the reference air kerma ($K_{a,r}$) exceeds 3 Gy. If the $D_{skin,max}$ exceeds 3 Gy, the patient is followed up for any skin effects. An audit was undertaken of these results over a 2-year period.
Results: From January 2020 to December 2021, 140 patients who underwent INR procedures had a $K_{a,r} > 3$ Gy, 66 resulted in a calculated $D_{skin,max} > 3$ Gy, and 45 were successfully followed up. Twenty patients (44%) reported no skin effects and 25 (56%) reported skin effects, which were almost exclusively epilation. The mean (range) $D_{skin,max}$ for patients with no reported skin effects and those with observed skin effects was 4.6 Gy (3.0–11.1 Gy) and 4.2 Gy (3.0–7.0 Gy), respectively.
Conclusion: These results demonstrate that temporary epilation was observed in 56% of patients, in a cohort of 45 patients who underwent an INR procedure with calculated $D_{skin,max} > 3$ Gy and successful follow-up. The results support evidence in the literature that suggests the approximate threshold for temporary epilation reported by the International Commission on Radiological Protection (ICRP) may be too high for incidence of this effect, specifically on the scalp, when $D_{skin,max}$ is calculated from $K_{a,r}$ (using commonly used corrections and assumptions in the calculation).

Key words: neurointerventional radiology; radiation; temporary epilation.

Introduction

Advances in device technology and novel techniques[1–4] have driven the expansion of interventional neuroradiology (INR) by offering improved treatment options for a wide range of neurovascular conditions, such as aneurysm and arteriovenous malformation treatment as well as endovascular treatment for acute ischaemic stroke due to arterial occlusion. Increasingly, these conditions are being successfully managed by INR with outcomes that benefit both the patient and the Australian health care system.[5,6] The ageing population in addition to the frequency of neurovascular disorders[7] have significantly increased the demand for INR procedures within Australia.

Gold Coast University Hospital (GCUH) is a major centre of INR and is one of the leading providers of comprehensive endovascular treatment for patients with severe and life-threatening brain aneurysms and acute ischaemic stroke. This high acuity setting requires an increasing number of long and complex procedures, potentially resulting in a high radiation dose to the skin. The local protocol for patient follow-up after a high radiation dose from complex interventional procedures is derived from international and national guidance. The International Commission on Radiological Protection (ICRP) reports approximate single-dose thresholds and time of onset for the reaction of skin to ionising radiation delivered in diagnostic fluoroscopic exposures in publication 118.[8] This publication lists tissue reactions

of early transient erythema at 2–24 h of onset with an approximate threshold of 2 Gy, temporary epilation at approximately 3 weeks of onset with an approximate threshold of 3 Gy, main erythema at approximately 1.5 weeks of onset with an approximate threshold of 6 Gy and an increased severity of tissue reactions as doses increase beyond 6 Gy. In this context, the threshold doses are considered to be near to the estimated dose for 1% incidence of the specified tissue reaction. The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) safety guide for radiation protection in diagnostic and interventional radiology (RPS 14.1)[9] states the physician or referrer should follow up any patient receiving over 3 Gy estimated skin dose, in reference to the ICRP published approximate thresholds. In addition, the ARPANSA National Directory for Radiation Protection[10] requires that high radiation doses (high skin dose defined as 6 Gy or above) and any diagnostic procedure resulting in an observable acute radiation effect be reported to the Australian Radiation Incident Register (ARIR). This practice is in line with international recommendations.[11,12]

At GCUH, there was a perception that radiation-induced epilation was reported at a greater incidence than would be expected according to ICRP report 118. Therefore, using patient follow-up data routinely collected at our institution, this study aims to quantify the association of radiation-induced epilation following interventional neuroradiology (INR) procedures and compare the peak skin dose ($D_{skin,max}$) threshold to published values.

Methods

GCUH is a large tertiary hospital, with two interventional suites utilising one Philips Allura Xper FD20 single plane and one Philips Allura Xper FD20/20 biplane system (Philips Healthcare, Andover, MA), with INR procedures almost exclusively performed on the biplane system. INR procedures performed are approx. 45% diagnostic (e.g., cerebral angiogram) and approx. 55% involving treatment (e.g., endovascular aneurysm coil embolisation, flow-diverting stent, liquid polymer embolisation of arteriovenous malformations and dural arteriovenous fistulas).

Typical acquisition parameters for INR procedures are kilovoltage in the range 65–85 kVp, 12.5 frames/second, 5 ms pulse width, 0.1 mm Cu and 1.0 mm Al filtration.

The routine patient follow-up workflow for all INR procedures at GCUH is based on the above guidance from ICRP[8] and ARPANSA[9] and is likely to be similar to other centres both nationally and internationally. A summary of the workflow is detailed in Figure 1. $D_{skin,max}$ is calculated by a medical physicist if the cumulative reference air kerma ($K_{a,r}$) displayed by the fluoroscopic system exceeds 3 Gy.

System displayed $K_{a,r}$ is the cumulative air kerma at the interventional reference point (IRP) which is 15 cm below isocentre and defined to approximate the skin entrance point for a body procedure if the patient is positioned at the isocentre. The system reported $K_{a,r}$ from each radiation event in the Digital Imaging and Communications in Medicine (DICOM) radiation structured dose report (RDSR) is utilised for $D_{skin,max}$ estimation. The system kerma-area-product (KAP) accuracy is measured during annual system performance tests, and a correction for KAP accuracy, which is specific to the fluoroscopic system and x-ray tube, is applied to the $K_{a,r}$ for each radiation event. Each value is then distance corrected from the IRP to the skin entrance point in the reference model, with the patient head modelled as a 20 cm diameter cylindrical phantom positioned at isocentre. This is a reasonable assumption as the interventional neuroradiologists always aim to locate the patient at isocentre for optimal positioning during procedures with a biplane fluoroscopy unit. A beam length correction for each event is also incorporated to account for the longer distance travelled by the radiation beam towards the periphery of the cylindrical phantom relative to the middle of the beam. A fixed backscatter factor of 1.4 is applied to each event as well as a bed transmission factor of 0.75 for radiation fields that intercept the patient table. The mattress utilised on the Philips Allura Xper system is made of slow recovery foam with a density of 58 kg/m^3 and a thickness of 7 cm. Projection angles obtained from the RDSR are sorted into 5° bins in both the LAO (left anterior oblique)/RAO (right anterior oblique) and CAUD (caudal)/CRAN (cranial) planes. These projection bins in conjunction with field sizes, obtained from dividing the KAP by the $K_{a,r}$ from the RDSR, are used to build up a plot of overlapping fields (dose map) incident on the cylindrical head phantom, which is used to estimate the magnitude and location of $D_{skin,max}$ on the patient. There is no correction for table movement during the procedure. A summary of the steps taken to calculate $D_{skin,max}$ and an example of a generated dose map are shown in Figure 2.

If the calculated $D_{skin,max}$ exceeds 3 Gy, the interventional neuroradiologist who performed the procedure is informed of the potential skin effect, timing of onset and the estimated location from the generated dose map. The proceduralist follows up the patient at the appropriate time, typically by telephone consultation, to determine whether skin effects have been observed and if required, provides advice and reassurance to the patient. The state regulator is informed, if required ($D_{skin,max}$ >6 Gy or observable acute tissue reaction[10]).

A clinical audit was performed over a 24-month period from 1 January 2020 to 31 December 2021 of all patients who underwent an INR procedure and were followed up for potential skin effects. Data collected include the procedure type, date of procedure, system

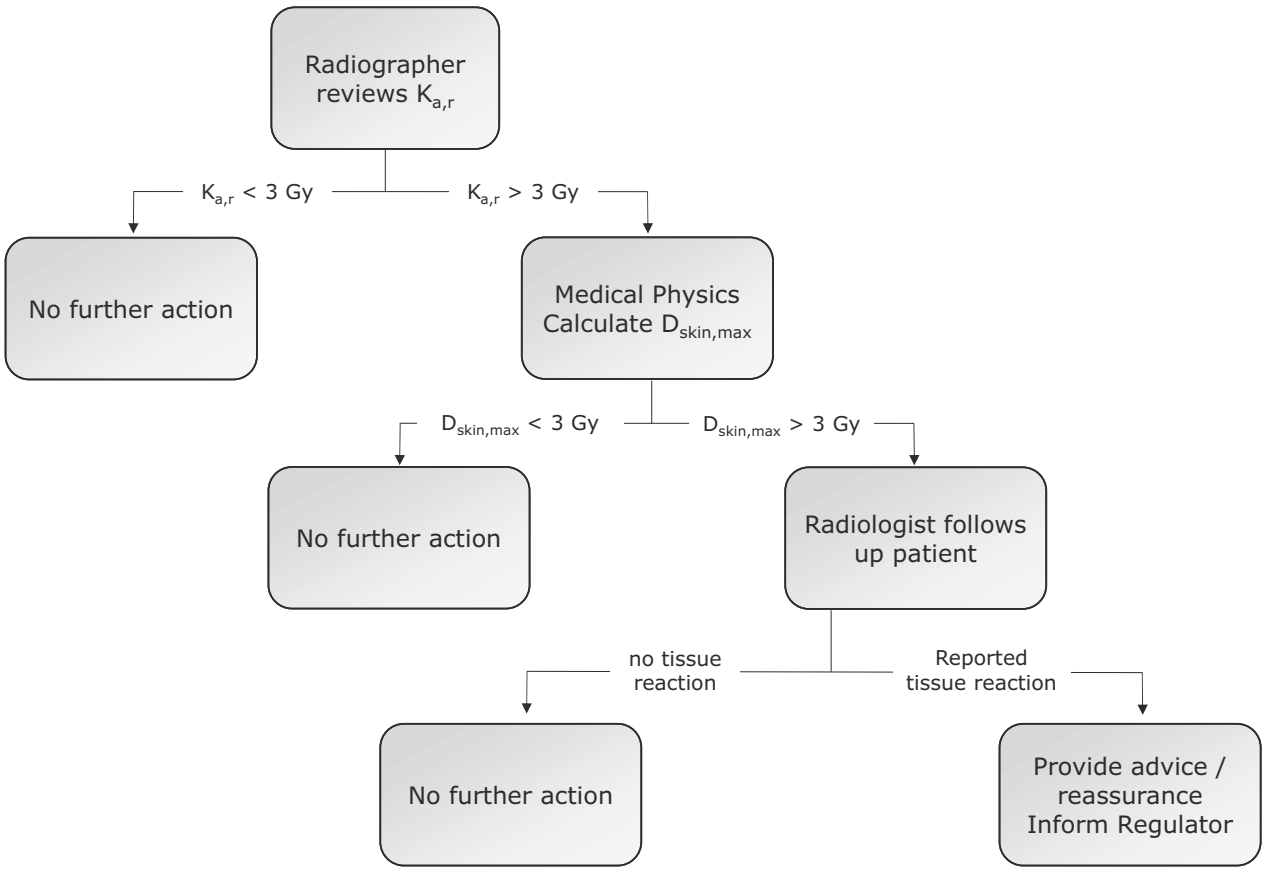

Fig. 1. Workflow for high skin dose follow-up at GCUH.

reported $K_{a,r}$, calculated $D_{skin,max}$, date of follow-up and result of follow-up which was categorised as unknown (patient unable to be contacted), deceased (patient passed away prior to follow up), no observed skin effects and reported skin effects. Where skin effects were reported by the patient, the effect and location of the effect were recorded. Results are reported by absolute number and % in each follow-up category. Descriptive statistics (mean, range) were used to report $D_{skin,max}$ in the no observed skin effect and reported skin effect categories, and a chi-squared test of independence was used to determine any association between $D_{skin,max}$ and likelihood of an observation skin effect above 3 Gy.

For the last 6 months of the study period, patients undergoing INR procedures with a calculated $D_{skin,max}$ 2–3 Gy were also followed up for any skin effects, in addition to those with $D_{skin,max}$ >3 Gy. The same $K_{a,r}$ trigger (>3 Gy) for calculation of $D_{skin,max}$ was used for this additional patient cohort due to ease of implementation (no change to standard procedure). Data from this additional patient cohort are reported separately using descriptive statistics.

Results

Over a 24-month period from 1 January 2020 to 31 December 2021, 1123 INR procedures were performed at GCUH and, of these, 614 were scheduled primarily as INR procedures involving a treatment (e.g., coil and embolisation). Of these scheduled INR procedures, 140 (23%) had a $K_{a,r}$ of greater than 3 Gy, and of those, 66 (47%) resulted in a calculated $D_{skin,max}$ of greater than 3 Gy. For patients with a $D_{skin,max}$ >3 Gy, 9 (14%) were deceased prior to the follow-up date, 12 (18%) were unknown (patient could not be contacted), and the remaining 45 (68%) were successfully followed up by the interventional neuroradiologist for potential skin effects. Follow-up involves contacting the patient on or soon after the approximate onset of skin effects and was performed at a median follow-up period of 5 weeks (range 2–30 weeks). Of the patients who were successfully followed up, 20 (44%) reported no observed skin effects, and 25 (56%) reported observed skin effects, which were epilation (25/25) and erythema (2/25). A summary of these results is shown in Figure 3. In addition, Table 1 includes a breakdown (number and %) of

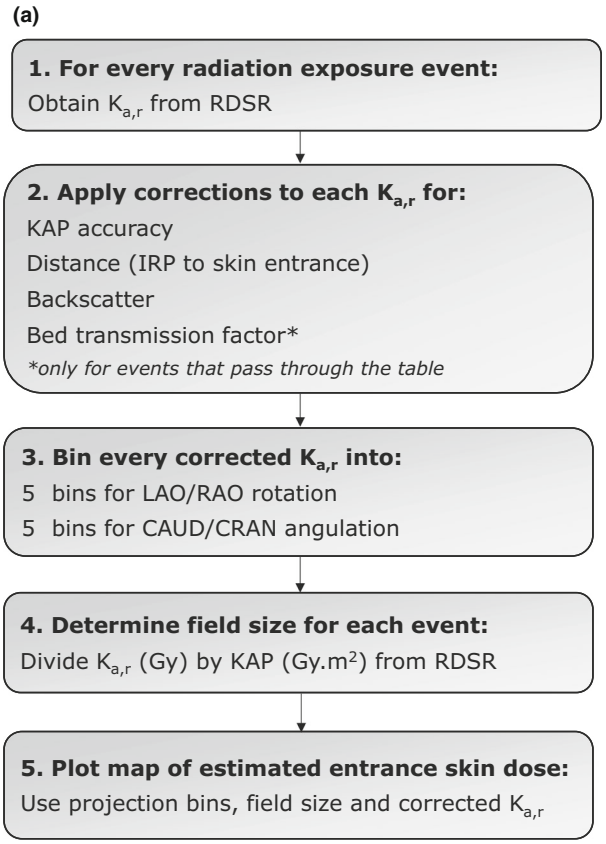

Fig. 2. (a) Summary of steps taken to calculate $D_{skin,max}$ from $K_{a,r}$ and (b) example of a plot of estimated total entrance skin dose (mGy).

INR procedures performed and INR procedures resulting in an observable skin effect, during the audit period.

Epilation was generally reported as focal patchy areas of alopecia (23/25) over areas ranging from 1–2 cm up to 10 cm diameter, as described by the patient. In the remaining 2/25 patients, the temporary epilation was reported as hair thinning rather than patches of hair loss (excessive hair in a hairbrush or hair detected on a pillow). In general, the location of the hair loss corresponded with the estimated location of the effect based on the projections used during the procedure and all were associated with head hair, rather than facial hair. In the two cases where erythema was reported, this was described as (i) skin redness on the left scalp at the back of the head and (ii) mild erythema at the back of the head. The latter case also reported mild tenderness when washing the hair.

The mean (range) of $D_{skin,max}$ for no reported tissue reaction was 4.6 Gy (3.0–11.1 Gy) and for reported tissue reactions was 4.2 Gy (3.0–7.0 Gy). Table 2 presents a further breakdown of patients reporting a tissue reaction for $D_{skin,max}$ increments of 1 Gy above the follow-up threshold of 3 Gy. The system reported $K_{a,r}$ range is also included for information. A chi-square test of independence showed that there was no significant association in this cohort between $D_{skin,max}$ and presence of observed skin effect above 3 Gy (chi-squared = 1.098; *P*-value = 0.78; $n = 45$).

For the last 6 months of the study period, patients undergoing INR procedures with a calculated $D_{skin,max}$ between 2 and 3 Gy were also followed up for any skin effects (note the $K_{a,r}$ threshold for $D_{skin,max}$ calculation remained at 3 Gy for this period). 13 additional patients required calculation of $D_{skin,max}$ during the 6-month period. 12 patients had a $D_{skin,max}$ between 2 and 3 Gy requiring follow-up, and only one patient had a $D_{skin,max}$ <2 Gy. Out of the 12 patients requiring follow-up, two were unable to be contacted and of the remaining 10, 7 (70%) reported no effects and 3 (30%) reported some degree of epilation with no pain or erythema.

Discussion

Our results, summarised in Figure 3, show for patients undergoing INR procedures at GCUH, temporary epilation was observed in approximately 50% in patients with estimated $D_{skin,max}$ >3 Gy, which is significantly greater than published thresholds.[8] As temporary epilation is classified as a tissue reaction, it is anticipated both the incidence and severity (duration) of the effect increases with dose, above a threshold dose. Therefore, it would be expected that patients with higher calculated $D_{skin,max}$ would show increased incidence of epilation. However, a chi-squared test of independence confirmed there was no significant associated in proportion of patients with and without epilation with absolute $D_{skin,max}$ up to approximately 6 Gy, in the patient cohort in this study (see Table 1).

Furthermore, three cases of temporary epilation (out of 10 patients successfully followed up) were detected in the extended patient cohort during the last 6 months of the study period, including patients with calculated $D_{skin,max}$ between 2 and 3 Gy. In this extended patient cohort (2–3 Gy), epilation was observed in 30% of patients which does demonstrate a reduced incidence compared patients with $D_{skin,max}$ >3 Gy. The reported effects in this cohort also indicate the severity of the epilation decreases with lower doses. One patient reported finding excess hair on the pillow, the 2nd patient reported increased hair falling out while brushing, and the 3rd patient simply reported hair loss, with no other details. The mechanism for temporary epilation due to radiation damage is the result of a transient loss of stem cells at the base of the hair follicles, which result in a transient reduction in diameter of the hair. After about 30% reduction in diameter, the hair distal to the thinned sections are likely to snap off, giving the appearance of epilation, prior to regrowth of the hair to a normal diameter.[13] This indicates decreased reduction in hair diameter at the lower $D_{skin,max}$ of 2–3 Gy may have resulted in less hair breaking, giving a milder appearance

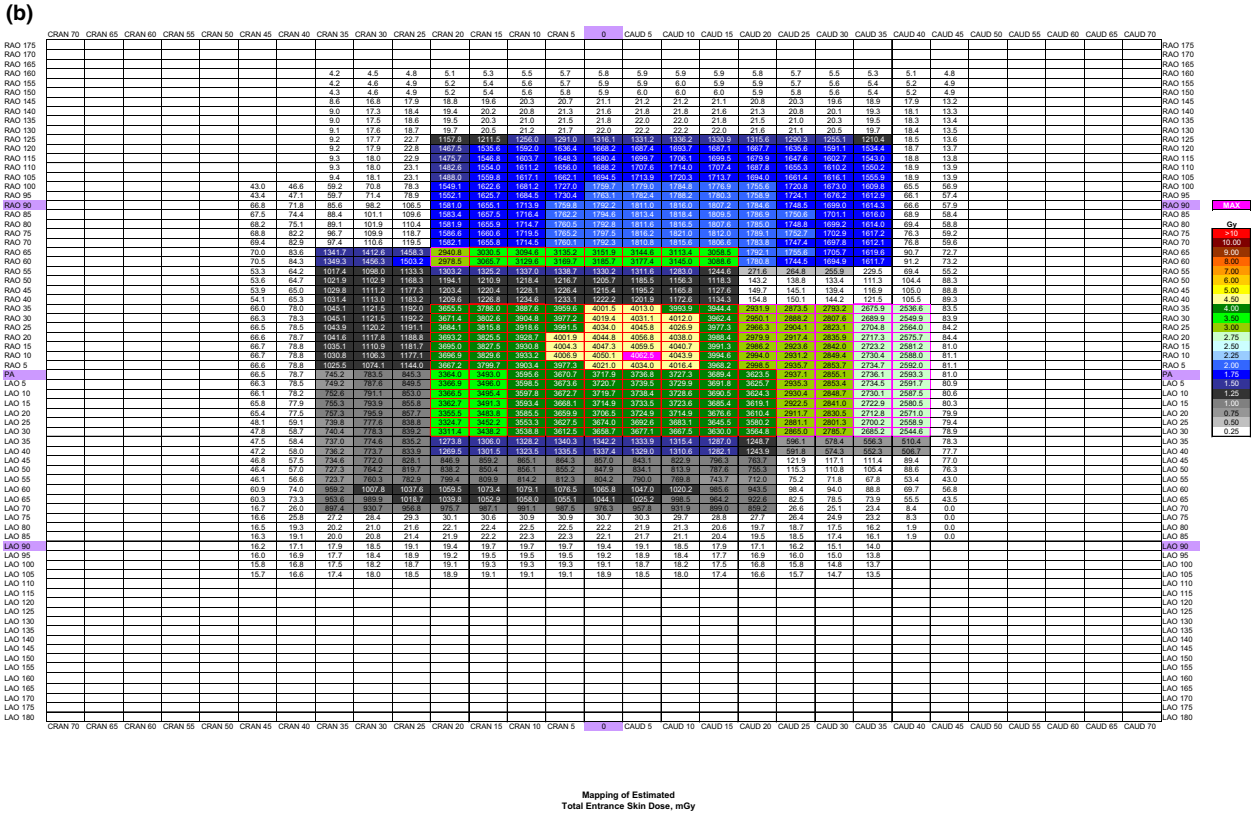

Fig. 2. (Continued)

of the epilation. It should be noted that there is a risk that some procedures with $D_{skin,max}$ >2 Gy were be missed using a $K_{a,r}$ threshold of >3 Gy. Based on historical data including all INR studies during the trial period, 85% of procedures have a $K_{a,r}/D_{skin,max}$ ratio of 0.67 or less, meaning 15% of procedures with $D_{skin,max}$ >2 Gy may be missed at our institution when using a $K_{a,r}$ threshold of >3 Gy.

A further key finding of this study is only two reports of erythema despite the lower published approximate threshold of 2 Gy (early transient erythema) compared to temporary epilation (3 Gy).[8] The estimated $D_{skin,max}$ was 3.6 Gy and 4.0 Gy, and the erythema was localised to the 'back of the head' for both cases. As the results are reported as part of a retrospective audit, it was not clear if the location of the erythema was on the scalp or instead near the nape of the neck.

Table 2.2 from ICRP report 118[8] reports the approximate threshold dose for various potential reactions of the skin and lens of the eye from fluoroscopic exposures, where the threshold doses are considered to be near the estimated dose for 1% incidence of the specified tissue reaction. This table is taken from ICRP report 85,[14] which is based on information from Wagner and Archer,[15] with reference to Hopewell.[16] ICRP report 85 includes three published case reports from INR procedures all demonstrating temporary epilation,[17–19] with estimated $D_{skin,max}$ above 3 Gy (6.6 Gy, 4.2 Gy and 3–4 Gy, respectively). Alopecia and epilation were the only reported skin effects (erythema was not mentioned), and it was observed that more severe skin effects were not reported. Several other case studies have been published,[20–31] specifically from the neurointerventional literature, reporting temporary epilation with no erythema. These 18 articles reported a total of 39 case studies. One stated an estimated $D_{skin,max}$ of 2 Gy, eight stated $D_{skin,max}$ >3 Gy, one stated $D_{skin,max}$ >4 Gy, and $D_{skin,max}$ was not mentioned in the remaining 29 case studies. There was also limited information on rate of incidence, as most studies reported their findings as isolated cases.

Table 2.5 from NRCP Report No. 168, 2010[12] gives a summary of skin and hair effects as a function of dose and time for a single-delivery radiation dose to the skin of the neck, torso, pelvis, buttocks or arms and importantly includes a footnote that the table does not apply to the skin of the scalp. NCRP 168 references published studies which report the scalp is relatively resistant to general skin effects (erythema, desquamation, etc.) compared to other more sensitive anatomical sites such as the anterior aspect of the neck.[20,32] In addition, epilation on the scalp is reported to be present at lower doses

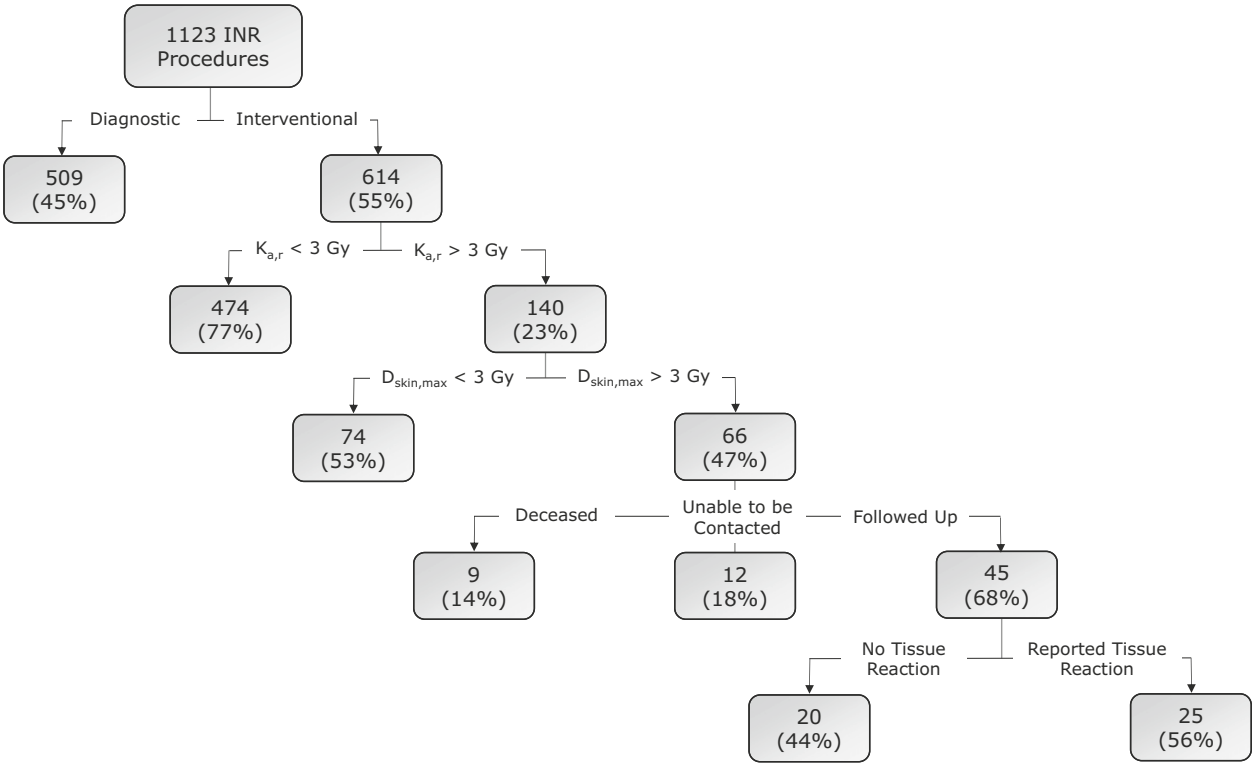

Fig. 3. Summary of patient follow-up results between January 2020 and December 2021.

Table 1. Total number (%) of INR procedures performed and number (%) of procedures resulting in an observable skin effect, during the audit period for $D_{skin,max}$ >3 Gy

INR procedure	Total performed, *n* (%)	Observable skin effects, *n* (%)
Thrombectomy	251 (41%)	1 (4%)
Aneurysm coil embolisation	135 (22%)	11 (44%)
Intracranial stent	97 (16%)	5 (20%)
Embolisation	74 (12%)	8 (32%)
Verapamil	57 (9%)	0 (0%)
Angioplasty	4 (1%)	0 (0%)

Table 2. Summary of reported tissue reactions by $D_{skin,max}$ range.

$D_{skin,max}$ Range	$K_{a,r}$ Range	Total patients	No observed skin effects	Reported skin effects
3–4 Gy	3.9–8.2 Gy	25	12 (48%)	13 (52%)
4–5 Gy	6.5–9.8 Gy	10	3 (30%)	7 (70%)
5–6 Gy	5.5–9.3 Gy	4	2 (50%)	2 (50%)
>6 Gy	9.2–12.8 Gy	6	3 (50%)	3 (50%)
>3 Gy (total)		45	20 (44%)	25 (56%)

than other areas of the body that also have some hair coverage, such as the face, chest and back.[20,33] This is clearly demonstrated in Figure 1 published by Balter 2010,[13] which shows radiation injury in a 60-year-old woman, demonstrating epilation of the scalp with no erythema, while the adjacent neck displays erythema.

The results from this study support evidence in the literature that the scalp is relatively resistant to erythema but more sensitive to epilation compared to other areas of the body, and approximate skin dose thresholds for transient erythema and temporary epilation may not apply to the scalp. This study is unique in reporting the number of INR procedures performed at a single centre, practising consistent patient follow-up, calculating $D_{skin,max}$ for all followed-up patients and reporting both cases of no observed skin effects and cases with observable skin effects (erythema, epilation).

The interventional neuroradiologist who was involved with follow-up observed that the patients were often unaware their epilation was related to the procedure. Despite information on risks of skin effects being included on standard consent forms, patients may not take in or remember this information, which may be attributed to stressful situation of undergoing a high-risk procedure or an emergency scenario. Patients may attribute the hair loss to stress or medication and are concerned the effect will be permanent, all of which can cause further anxiety. The follow-up provides a clear explanation to the patient about the origin of the effect,

as well as reassurance that the effect is temporary and no change to medication or any other external factors is required. These results suggest targeted advice for patients who have undergone INR procedures prior to discharge, around the likelihood, severity and location of temporary epilation may be helpful to education patients prior to the appearance of epilation. By reviewing the relationship between $K_{a,r}$ and estimated $D_{skin,max}$, the likelihood of temporary epilation can be estimated based on $K_{a,r}$ for specific procedure types and fluoroscopic equipment, so patients at risk can be provided the information immediately after their procedure. Estimation of $D_{skin,max}$ and subsequent patient follow can still occur, but provision of this targeted advice should catch the majority of patients at risk, will prepare them for the likelihood of temporary epilation and potentially reduce any anxiety and stress they may experience.

There are several limitations in this study. Despite neuroradiologists always aiming to locate the patient at isocentre for optimal positioning, the calculation of $D_{skin,max}$ does not consider table movement (vertical, longitudinal or lateral) that may occur during the procedure which will affect the accuracy of the calculation. A standard backscatter factor of 1.4 is used, which is a typical value applied for fluoroscopic body exams. This is a limitation of the calculator as the actual backscatter factor for individual procedures will depend on beam quality (beam filtration and kVp) and field size, and a standard factor of 1.4 will likely result in an overestimate of $D_{skin,max}$ for harder beam qualities typically used in INR procedures (compared to body regions). In addition, the cranial bone layer (skull) will likely absorb low-energy photons, attenuating both primary and backscattered photons, which may also contribute to a lower BSF and potential overestimate the $D_{skin,max}$. The stated methodology does not account for the difference between air kerma and dose absorbed in tissue (between 1.04 and 1.07 correction, depending on beam quality) which will result in an underestimate of $D_{skin,max}$ of between 4% and 7%. The patient is modelled as a 20 cm cylindrical phantom which does not accurately reflect individual patient size or shape. The standard bed transmission factor of 0.75 was validated through measurements for typical acquisition factors, but will again vary depending on beam quality and is not accounted for.

The overall calculation of $D_{skin,max}$ therefore contains significant uncertainties. Our institution participated in an open survey within Australia comparing measured dose from calibrated radiochromic film placed on the bed under the patient during several real-world clinical interventional procedures.[34] $D_{skin,max}$ was calculated from the associated RDSR from eight of the cases (1× abdominal stent, 3× abdominal embolisation, 1× cholangiogram, 3× abdominal angiograms) using the same method as described above. Over the eight cases, the median absolute deviation of absolute $D_{skin,max}$ from the measured film dose (gold standard) was 10% (range 3–36%) with only one case exceeding ±21%. It should be noted that the clinical cases were all abdominal; therefore, no direct validation for $D_{skin,max}$ calculation has been performed on cerebral clinical cases. The major difference in the local calculation method is that the patient is modelled as a 30 cm diameter cylindrical phantom for abdominal procedures and a 20 cm diameter cylindrical phantom for cerebral procedures. The remaining corrections as described above are consistent between the two body regions. It should also be noted that the corrections applied are relatively simple, well documented and likely to be typical of corrections performed in other centres in the estimation of $D_{skin,max}$.

Although 45 patients were successfully followed up, an additional nine were deceased prior to follow-up and 12 were unable to be contacted. If these 21 patients were successfully followed up, the number of observable skin effects may be significantly altered. Finally, all observed skin effects were self-reported by the patient, and there was no follow-up by the interventional radiologist in the clinic to confirm the observations. Specifically, the lack of observation of transient erythema (approximate onset 2–24 h) may be impacted by the median follow-up period (5 weeks).

In conclusion, our results demonstrate that temporary epilation was observed in 56% of patients, for a cohort of 45 patients who underwent an INR procedure at GCUH, had a calculated $D_{skin,max}$ >3 Gy and were successfully contacted for follow-up. In addition, less severe temporary epilation was observed in 30% of patients in a smaller cohort of 10 patients with calculated $D_{skin,max}$ between 2 and 3 Gy.

These results support evidence in the literature that suggests the approximate threshold of 3 Gy for temporary epilation reported by the ICRP and widely accepted in national and international radiation safety legislation and guidance documents may be too high for the incidence of this effect specifically on the scalp. In addition, the results support evidence that suggests the approximate threshold of 2 Gy for erythema may be too low for irradiation of skin on the scalp. Dosimetric uncertainties and variability in individual sensitivity mean thresholds for tissue reactions are only approximate. However, the data reported in this study demonstrate that greater familiarity in the relationship between the number of observed cases of epilation and locally calculated $D_{skin,max}$ is important to provide appropriate, proactive advice nad follow-up to patients undergong INR procedures, to alleviate potential anxiety and distress caused by unexpected hair loss.

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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