10-11 (2024) 100028

Contents lists available at ScienceDirect

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Full Length Article

Experimental measurement of dosimetric parameters relevant to radioactive needlestick injury

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ARTICLE INFO

Keywords:
Needlestick injury
Decontamination
Skin dose
Radiation protection

ABSTRACT

Nuclear medicine healthcare workers are exposed to the risk of radioactive needlestick injury. To quantify the severity of this risk, the activity deposited into the skin and the injury depth have been experimentally measured for input into skin dosimetry program VARSKIN+. Agar test objects were pierced by hand with a needle containing Tc-99m Hydroxymethylene Diphosphonate (HMDP). The deposited activity was measured by contamination monitor and converted into deposited volume. Injury depth was measured with a ruler by piercing the test objects with visible dye.

The median volume deposited into test objects without gloves was 100 ± 50 nl (standard error) (interquartile range (IQR): 50–320 nl). Through one glove, this was reduced to 50 ± 20 nl (IQR: 30 - 140 nl), however, the difference was not significant ($p > 0.1$). The volume deposited through two gloves was highly variable due to the increased force required to puncture. The median injury depth was 4.0 ± 0.4 mm (standard error).

Decontamination efficacy was investigated by rinsing alone, with hand soap and by application of decontamination agent RadiacWash. All decontamination methods were found to significantly decrease the activity deposited ($p < 0.001$). Test objects rinsed for 60 s had a mean reduction of 42 % ± 6 % (95 % confidence interval). There was no significant difference observed between decontamination methods. This may be due to differences in absorption time between the sample groups.

Skin dose estimates have been calculated in VARSKIN+ using the results of the experiment. For injuries without gloves, involving 1011 MBq/ml of Tc-99m HMDP, a skin dose of 11 ± 5 mSv (propagated standard error) was calculated. Immediate decontamination under running water is recommended to reduce the dose. Further research is encouraged to investigate the protection offered by gloves.

1. Introduction

Needlestick injuries that involve radiopharmaceuticals carry a radiation risk associated with embedding a radioactive substance within the skin. There is a wide awareness of the danger of contracting blood borne viruses from needlestick injury (NSI), however there are few publications relating to NSI involving radionuclides [1,2]. Staff groups at risk of radioactive NSI include those that dispense, administer and manipulate radiopharmaceuticals using a needle, such as radiopharmacists, nuclear medicine radiographers, technologists and physicists.

During the year 2019/20, approximately 400,000 nuclear medicine scans, 200,000 PET-CT scans and 45,000 SPECT scans were performed by the NHS in England [3], yet no data is currently available for radioactive needlestick injuries. National and global studies have investigated the incidence and underreporting of needlestick injuries [4–6]. The average prevalence reported in an international review was 3.7 sharps injuries per 100 healthcare workers per year [7].

UK legislation, the Ionising Radiation Regulations 2017 (IRR17) [8],

Abbreviations: CT, computed tomography; HCW, healthcare worker; HU, hounsfield unit; ICRP, International Commission on Radiological Protection; IRR17, Ionising Radiation Regulations 2017; IQR, interquartile range; NSI, needlestick injury; PPE, personal protective equipment; ROI, region of interest; SDE, shallow dose equivalent; Tc-99m, technetium-99m; (Tc-99m) HMDP, hydroxymethylene diphosphonate; TMP, Tissue Mimicking Phantom.

This research did not receive any specific grant from funding agencies in the public, commercial or not-for-profit sectors.The research on which this paper is based won best poster award at the South West Medical Physics and Clinical Engineering Meeting, Exeter, UK, 9 June, 2023.

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https://doi.org/10.1016/j.ipemt.2024.100028
Received 22 January 2024; Received in revised form 17 May 2024; Accepted 22 May 2024
Available online 23 May 2024
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mandates that the nature and magnitude of radiation risks are evaluated in the radiation risk assessment. Therefore, the risk of needlestick injury should be included with a dose estimate to inform safety measures and the classification of staff working with radiopharmaceuticals. The recent release of dosimetry program VARSKIN+ version 1 contains a new module called WoundDose [9]. This module is capable of modelling radiation sources embedded within the skin and calculating skin dose using Monte-Carlo methods. The program requires the input of parameters including deposited radioactivity and injury depth.

This project aimed to devise representative values of deposited volume and injury depth for input into VARSKIN+, via experimental measurement. The project also aimed to investigate the potential reduction in activity transferred through gloves (following similar research for non-radioactive substances [10–15]) and the reduction following decontamination procedures.

2. Methodology

The work was conducted in three phases:

Volume of radiopharmaceutical deposited in a NSI

A key parameter in needlestick dosimetry is the activity of the radiopharmaceutical deposited in the skin. This is related to the volume of radiopharmaceutical deposited, according to the relationship: *Activity* (Bq) = *Activity Concentration* (Bq/ml) x *Volume* (ml). Hence, the deposited activity can be estimated for a NSI involving any activity concentration if a representative deposited volume is known. The protection offered by gloves in reducing the volume deposited was also investigated.

Decontamination efficacy

Decontamination procedures recommended in the event of NSI are similar to those for skin surface decontamination, with the addition of encouraging bleeding by squeezing the affected site. This experiment measured the reduction in deposited volume following NSI due to rinsing with water alone, with hand soap and applying decontamination agent, and compared the efficacy of the different techniques.

Injury depth

The injury depth is the skin depth to which the contaminated needle penetrates. This impacts skin dose because it affects the source geometry with respect to the sensitive skin layer. The shallow dose equivalent (SDE) reduces with injury depth for a constant deposited activity, as the source is distributed more thinly through the sensitive skin layer.

2.1. Phantom choice and preparation

A review of the literature surrounding Tissue Mimicking Phantoms (TMPs) details the main materials used to simulate human skin. Surface and mechanical properties were deemed most relevant to NSI. The review states that '*Water-gelatine solutions closely simulate the density and viscosity of human tissue*' [16]. For ease of preparation and procurement of materials, agar was chosen as the phantom material.

To determine the most suitable concentration of agar, studies measuring the elasticity of the human finger were cross-referenced with studies measuring the elasticity of agar samples across a range of concentrations. Based on the results of two studies measuring the elasticity of participants' fingers, a range of 30–120 kPa was expected to be representative of the elasticity of finger skin [17,18]. The concentration of agar used in this project was close to 1.5 %, which corresponds to an elastic modulus of around 120–150 kPa [19,20]. Concentrations < 1 % did not solidify and were therefore impractical.

Validation of the phantom material was attempted via CT and elastography but was unsuccessful. The CT number of the agar phantom was much lower than that measured from clinical wrist scans (approximately 10 and 75 HU respectively). This was thought to be due to the high water content of agar. Elastography measurements were difficult to obtain and reproduce.

The agar solution was set in silicone moulds with dimensions similar to a human finger (7.6 cm (L) x 1.6 cm (H) x 1.6 cm (W)). This enabled the test objects to fit within gloves and stretch the material sufficiently, to test for reduced transfer of the radiopharmaceutical through gloves.

2.2. Measurement of deposited volume

The radiopharmaceutical used was Tc-99m HMDP with an initial activity of 449 MBq/ml. Tc-99m HMDP is used for bone scintigraphy scans, the most common diagnostic nuclear medicine scan as of 2019/20 [21]. The radiopharmaceutical was drawn into a syringe with a 23G needle and the agar test objects were pierced by hand, once each, without applying pressure to the plunger. 20 test objects were pierced without a glove layer, 20 within one glove and 20 within two gloves. The needle was primed every 2-3 punctures by applying light pressure to the plunger until the radiopharmaceutical was visible at the tip of the needle. It is understood that piercing by hand and priming the needle sporadically will introduce more variation in the measurements; this was intended to be representative of the variation in reality.

A Thermo Scientific Mini 900 contamination monitor was set-up in a clamp stand at a height of 14.0 $\pm$ 0.1 cm from the top of the test object, corresponding to a distance where all readings were within the monitor range. The monitor was set-up behind a lead screen to minimise background radiation levels. The set-up is visible in Fig. 1.

The activity in counts per second (cps) was recorded for each test object by positioning directly below the contamination monitor, pierced side upward. Reproducibility was assessed by measuring the same test object 5 times. For test objects pierced within one or two gloves, measurements were taken after glove removal. The gloves used were Mercator Nirylex Classic – medium-sized, nitrile, non-sterile, powder-free gloves with micro and fingertip texture of 2.8 mil (0.07 mm) thickness.

2.2.1. Data analysis steps

The following steps were taken to process the data collected:

1. Contamination monitor readings were background corrected
2. Background corrected readings were decay corrected to the reference time
3. Decay corrected readings were converted into MBq by application of a calibration factor

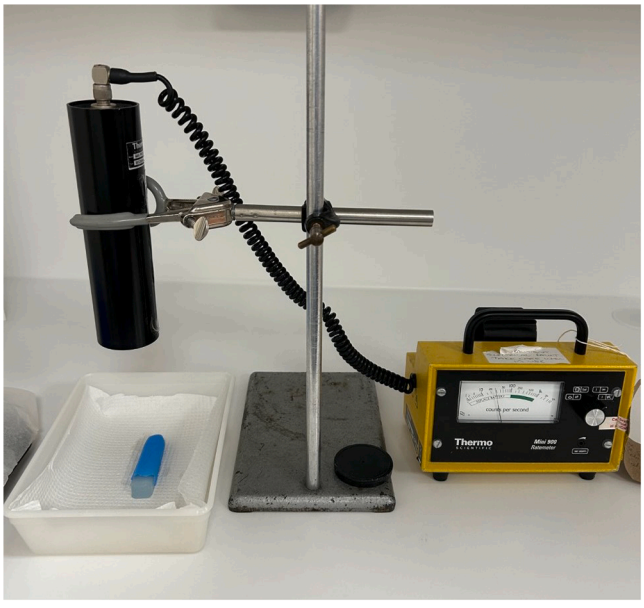

Fig. 1. Experimental set-up for activity measurements made with a Thermo Scientific Mini 900 contamination monitor.

4. Activity measurements were converted into volume by dividing by the activity concentration at the reference time

2.2.2. Contamination monitor calibration

A conversion factor for the contamination monitor (Bq/cps) was devised by scanning the test objects on a Siemens Intevo gamma camera, which has a known sensitivity factor. The test objects were positioned with the injury site closest to the detector, consistent with the contamination monitor set-up.

The gamma camera images were post-processed in Hermes Medical Solutions software by drawing Regions of Interest (ROIs) using a thresholding tool to contain the majority of counts from each needlestick. This is shown in Fig. 2. The SPECT-CT in Fig. 3 was used to identify the agar test object that each ROI corresponded to, in order to relate the contamination monitor reading. Only the sites with sufficient deposited activity were measured.

The relationship in Fig. 4 appears linear with an R^2 of 0.98. The gradient of the line gives a contamination monitor conversion factor of 0.00050 ± 0.00002 MBq/cps (95 % confidence interval). This factor was applied to all contamination monitor readings to convert into activity.

2.3. Measurement of reduction in activity due to decontamination

Three groups of 13 agar test objects were pierced with a needle contaminated with Tc-99m HMDP, using the techniques and set-up as described in 2.2. All test objects were pierced without a glove layer and decontaminated one at a time using the following methods:

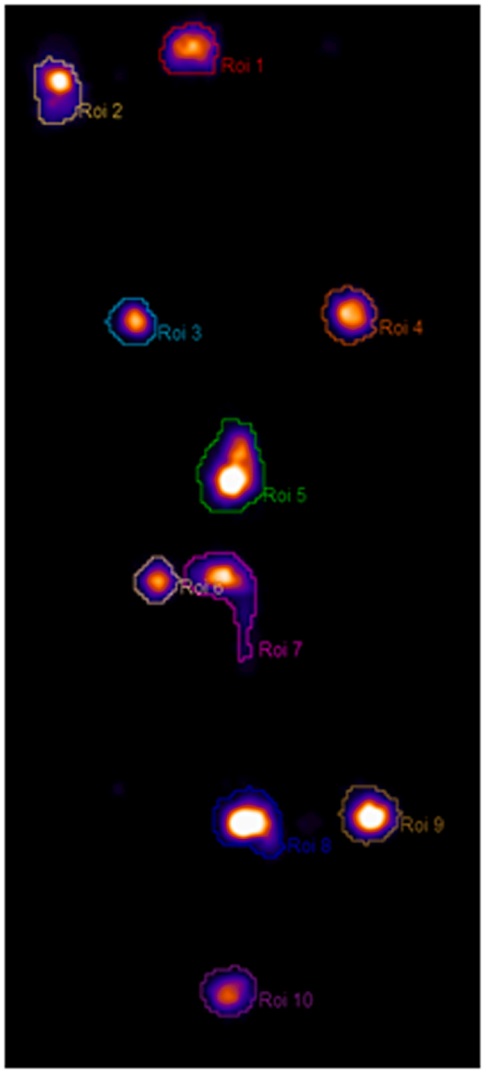

Fig. 2. Planar gamma camera image with ROIs around hot spots.

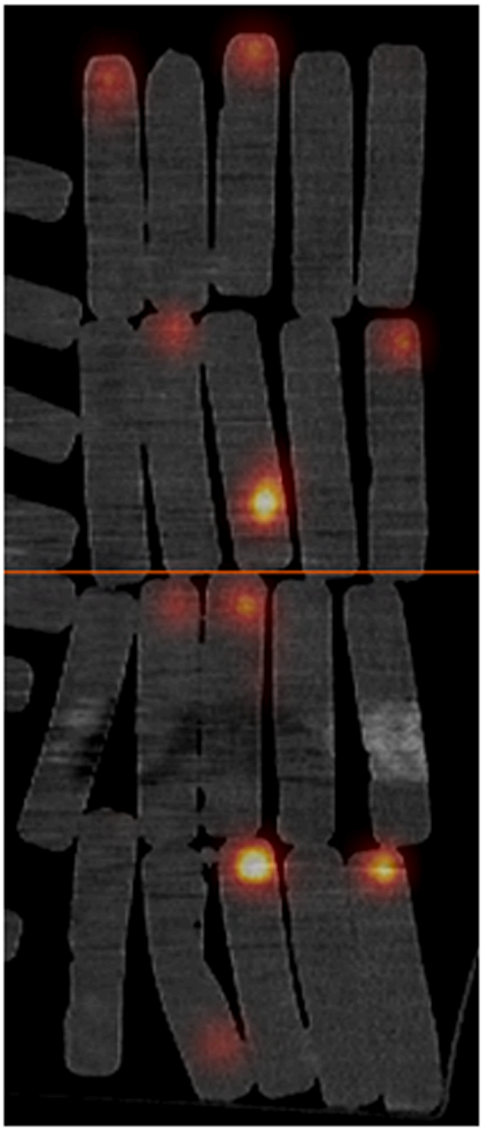

Fig. 3. SPECT-CT of agar test objects showing hot spots where contaminated needle pierced.

Group 1 – The test objects were rinsed under running water while being gently rubbed with a folded dishcloth. Activity measurements were taken after 10 s of rinsing, 30 s of rinsing, and 60 s of rinsing.
Group 2 – Hand soap was generously applied and massaged into the test object using a folded dishcloth. Additional soap was applied periodically while rinsing for 60 s.
Group 3 – Test objects were generously sprayed with decontamination agent RadiacWash #005-400 and left for 30 s (as per product instructions). The test objects were then rinsed for 60 s according to the procedure for Group 1.

Activity was measured before and after decontamination to quantify reduction. Cold tap water was kept running at a constant rate of approximately 20 ml/s throughout and there was no noticeable fluctuation in water temperature. A new dishcloth was used for each test object.

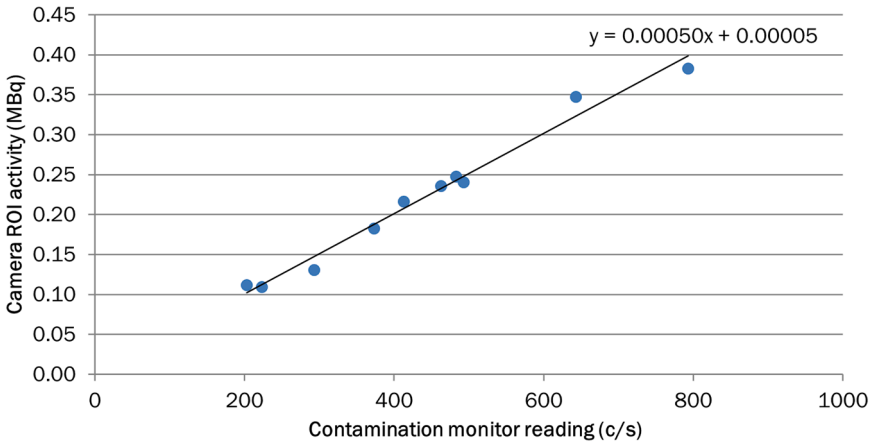

Fig. 4. relationship between the contamination monitor readings and the derived activity, as measured with ROIs on the gamma camera image.

2.4. Measurement of injury depth

The initial method chosen for injury depth measurement was to pierce test objects with CT contrast and measure the penetration depth on the CT image. The resolution of the Siemens Symbia Intevo Bold CT scanner (~ 0.3 mm [22]) was sufficient for measuring the expected depth. However, in practice, the volume of contrast present in the test objects from a NSI was too little to be visible in the image.

The implemented method for measuring injury depth was the use of visible dyes. Single-gloved test objects were pierced by hand with a 23G needle containing blue food colouring. Since most nuclear medicine workers are trained to wear at least one pair of gloves at all times, this was considered the most likely scenario for a NSI. The single glove layer also provided increased surface resistance to mimic the skin surface. The colourless test objects were cut open to measure the penetrated depth with a ruler, to the nearest 0.5 mm. Fig. 5 shows this process.

As observed in Fig. 5, it was suspected the dye absorbed and spread within the agar with time. This will have introduced measurement uncertainty and increased the observed injury depth. This was mediated by piercing and measuring the test objects in small batches.

2.5. Dose calculation

The WoundDose module in VARSKIN+ was used to calculate needlestick injury doses using the average values of deposited volume and injury depth. The deposited volume results were converted into deposited activities by assuming an activity concentration of 1011 MBq/ml.

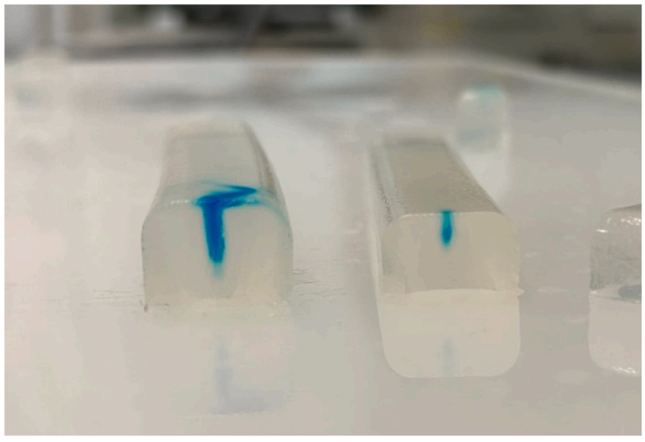

Fig. 5. injury depth measurements performed by piercing agar test objects with a needle containing blue dye and measuring penetration with a ruler.

This was the activity concentration of the Tc-99m HMDP used experimentally at the reference time of 9:18 (considered a typical clinical administration time). The parameters used in VARSKIN+ are shown in Table 1. Guidance on the WoundDose module can be found in NCRP Report No. 156 [23].

VARSKIN+ version 1.1 was used for this project. Version 1.0 contains an issue with the WoundDose Line Source model, resulting in underestimation [24]. This was resolved in version 1.1. Doses reported are the 'Total Dose (No Decay Correction)' value from the 'Dose Detail' window. In VARSKIN+ version 1.1, this value does in fact account for both physical and biological decay. Note, this may not be the case in future versions of VARSKIN+.

3. Results

3.1. Deposited volume

Fig. 6 shows a box plot of the deposited volume data, for test objects pierced without a glove layer, through one glove layer and two glove layers. Table 2 contains key figures. Statistical analysis was performed using IBM SPSS statistics [29].

The median volume deposited into test objects without gloves was 100 ± 50 nl, which lies within the range of average values published by

Table 1
Values of VARSKIN+ dosimetry parameters used in NSI dose estimates.

VARSKIN+ parameter	Value	Justification
Source Geometry Type	Line Source	As the source distribution in a NSI is unknown a worst case estimate is preferred. The line source model results in higher dose estimates since the activity is distributed through the sensitive skin depth.
Dose depth	0.07 mm	ICRP 103 states the depth that the annual skin dose limits apply to [25]
Injury depth	4.0 mm	Median value measured in this experiment
Averaging area	1 cm^2	IRR17 Schedule 3 states that annual skin dose limits apply to the dose averaged over a 1 cm^2 area [8].
Retention class	Weak	The biological half-lives of several common Tc-99m radiopharmaceuticals were considered and these were typically less than the 'weak' retention class of 0.4 days[a] [26,27].
Nuclide library	ICRP 107	ICRP publication 107 supersedes the data of publication 38 [28]
Dose measure	SDE	VARSKIN+ calculates the shallow dose equivalent (SDE), local dose equivalent and committed effective (and organ) dose equivalent [9]. For comparison with legislative skin dose limits, SDE is the applicable dose metric.

[a] Assuming the clearance rate is the same for NSI as typical administration.

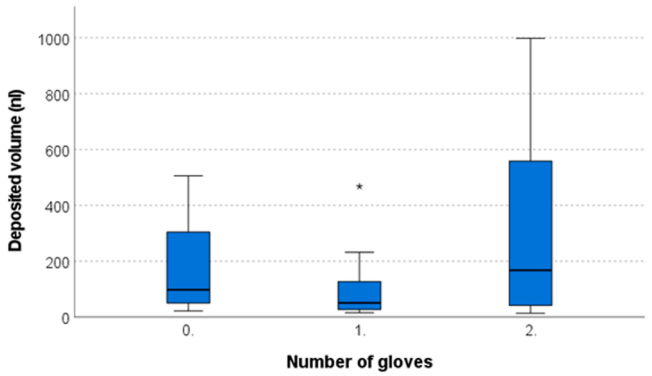

Fig. 6. Box plot of the calculated deposited volume in test objects without gloves, with 1 layer of gloves and with 2 layers of gloves.

Table 2
Median deposited volume results and interquartile range. Standard error of the median calculated using bootstrap method with $B = 300$ sets.

	Median deposited volume (nl) ± standard error of median	Interquartile range (nl)
No gloves ($n = 20$)	100 ± 50	270 (50–320)
Single glove ($n = 20$)	50 ± 20	110 (30–140)
Double glove ($n = 20$)	170 ± 140	540 (40–580)

other studies, 60 nl [11] to 2.5 µl [10]. This wide range indicates that study results are variable, even between studies using similar techniques. The median volume deposited through a single glove layer was 50 ± 20 nl, however the reduction is not significant (Kruskal-Wallis test: $p > 0.1$). The average volume deposited through a single glove lies within the range of other studies, 3.06 nl [12] to 386 nl [15], some of which found a significant reduction in volume transferred through gloves [10,12–14] [30].

3.2. Decontamination efficacy

With 60 s of rinsing alone, the contamination on the agar test objects was reduced on average by 42 % ± 6 % (95 % confidence interval). Using hand soap and decontamination agent did not improve the percentage reduction compared with rinsing alone, as shown in Fig. 7.

Friedman's 2-way ANOVA found significant reduction in activity for all decontamination methods ($p < 0.001$). A repeated measures ANOVA test was performed to assess the reduction in activity with rinsing time. This incorporates a Bonferroni adjustment for multiple comparisons. The results showed significant reduction between 0 and 10 s and 10–30 s, but not 30–60 s.

The Kruskal-Wallis ANOVA test found a significant difference in distribution between Group 1 (rinsing alone) and Group 3 (decontamination agent applied prior to rinsing) ($p = 0.038$, adjusted for multiple tests). This result may be due to differences in absorption time between the groups, given the samples were all contaminated at the beginning of the session. Fig. 8 shows a downward trend in the percentage activity reduction with absorption time, although the Pearson Correlation found weak significance ($p = 0.06$).

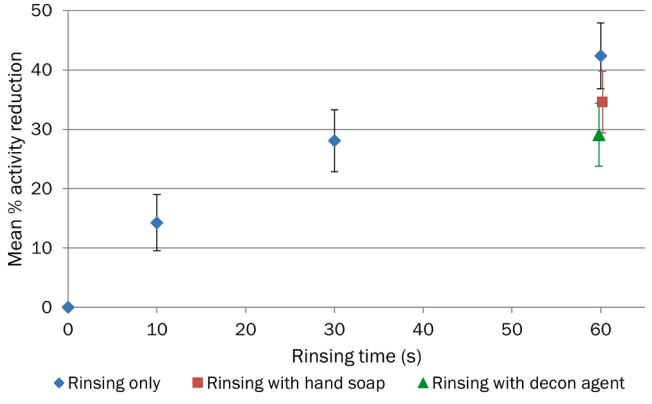

Fig. 7. Mean percentage activity reduction due to rinsing contaminated test objects for 10 s, 30 s and 60 s, with hand soap and decontamination agent for 60 s. Error bars represent the 95 % confidence interval. Data points at 60 s are intentionally offset to show error bars clearly.

3.3. Injury depth

A total of 85 injury depth measurements were taken. Five measurements ≥ 6 mm were excluded, as they originated from NSIs that penetrated the entire depth of the agar test object, considered unlikely in reality due to finger structures such as bone. The median value of injury depth was 4.0 ± 0.4 mm (standard error of the median using bootstrap method with $B = 300$) with an interquartile range of 2 mm. All data is displayed in Fig. 9.

3.4. Needlestick injury dose estimation in VARSKIN+

3.4.1. Estimated needlestick injury dose without gloves

Experiment 1 found a median deposited volume without gloves of 100 ± 50 nl, equivalent to a deposited activity of 0.10 MBq for an activity concentration of 1011 MBq/ml. The deposited activity and median injury depth of 4.0 mm were inputted into VARSKIN+ and a shallow dose equivalent (SDE) of 11 ± 5 mSv was calculated. Quoted uncertainties are the propagated standard error.

It is noted that the sensitive basal cell layer of the fingertip is known to be deeper (>160 µm) than the depth advised for skin dose estimates (70 µm) [31]. Setting the dose depth to 160 µm increased the estimated SDE to 12 mSv.

3.4.2. Estimated dose through a glove layer

The median volume deposited into test objects within a single glove was found to be 50 ± 20nl. This is 50 % of the volume deposited without gloves. Hence the estimated SDE was halved to 5 ± 2 mSv. The double glove data was considered too variable to provide a reliable dose estimate from VARSKIN+.

3.4.3. Dose reduction due to decontamination

Rinsing a contaminated NSI for 1 min resulted in an average reduction in activity of 42 %. This corresponds to an SDE of 6 mSv for

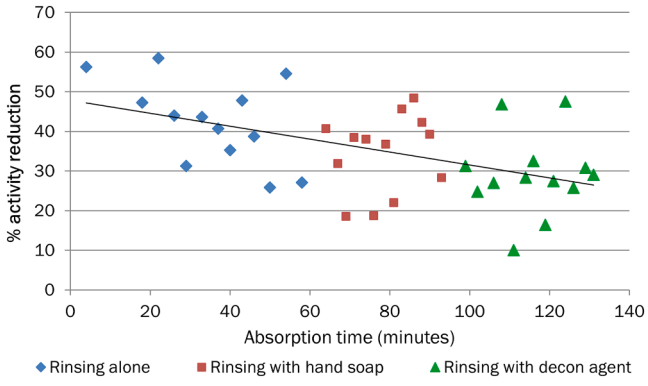

Fig. 8. Percentage activity reduction against absorption time for all groups of decontamination data.

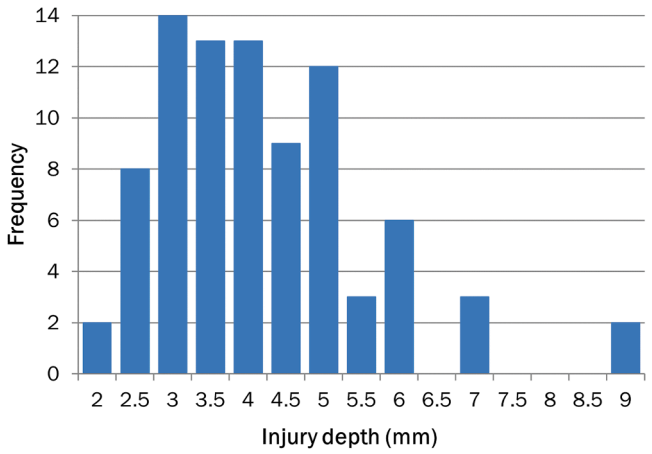

Fig. 9. Histogram of injury depth measurements.

NSIs occurring without gloves that are decontaminated immediately. This percentage reduction may not be applicable to NSIs occurring through gloves, as this involves a smaller initial quantity of radioactivity.

3.4.4. Worst case estimate

A shallow injury depth is applicable for estimating a worst case dose. Using the maximum deposited volume of 520 nl and the minimum recorded injury depth of 2 mm gave a worst case estimate of 105 mSv. However, a study reported that deeper injuries deposit more fluid [10], suggesting that this worst case combination is unlikely. It is suggested that a more likely combination for a cautious dose estimate would be the 75th percentile of the deposited volume data, 320 nl (in the absence of gloves), and the 25th percentile of the injury depth data, 3 mm. The estimated SDE in this case was 44 mSv.

4. Discussion

A commonly used resource in the assessment of skin doses is Delacroix's radionuclide handbook [32], where the closest approximation to NSI is a 0.05 ml droplet on the skin surface. This is 500 times larger than the median deposited volume found in this experiment (in the absence of gloves). This highlights the need for a specialised solution such as VARSKIN+ for NSI dose estimates. Using Delacroix's handbook, contamination of the skin surface with 0.05 ml of Tc-99 m 1011 MBq/ml (the same concentration used for the NSI dose estimates), assuming 1 min to clean the skin, results in a dose of 7.4 mSv. This is comparable in magnitude to the doses estimated for NSI.

Nuclear medicine workers are trained to always wear PPE when handling radiopharmaceuticals, as widely recommended [33]. The median volume transferred through a single glove layer was reduced from 100 nl ± 50 nl to 50 nl ± 20 nl. The reduction was not statistically significant, however the potential to reduce skin dose by half is notable. The double glove data showed greater variation than the other groups. When performing the experiment, there was a notable increase in the force required to puncture two glove layers by hand. This could have resulted in deeper injuries, which are reported to deposit significantly more fluid [10]. This may explain the increase in average deposited volume. It is possible that double gloving may reduce the probability of an NSI occurring due to the larger force required to pierce.

All decontamination methods investigated in this experiment were found to be effective, with an average reduction of 42 % following 60 s of rinsing. The results indicate that continued rinsing is an effective form of decontamination, with the first 30 s being the most effective. Other sources have reported larger activity reductions. A study which contaminated pig skin with Tc-99m HDP found a mean remaining activity of 2.48 % after 30 s of rinsing [34]. It is possible that the nature of a NSI embedding the radiopharmaceutical within the skin makes it more difficult to remove than surface contamination. Furthermore, a NSI case study presented at IPEM RPA Update 2021 [35] estimated an initial deposited activity of 12 MBq in 5 μl. Following decontamination, monitoring data equated to 2.2 MBq. This is a reduction in activity of 82 %. It is suspected that decontamination methods not investigated in this experiment, such as squeezing the fingertip to encourage bleeding, may further reduce the activity deposited.

Due to inconsistent absorption time between the sample groups, the different decontamination methods employed in this experiment cannot be directly compared. Absorption time was found to have a weak negative correlation with decontamination efficacy. Tc-99m has a relatively short absorption time and decontamination should commence within the first hour [36]. A study investigating skin surface decontamination reported increased remaining activity with absorption time, however this finding was not significant [34]. Further research into the effect of absorption time and the most effective forms of decontamination are encouraged.

For NSI occurring without gloves, a cautious skin dose estimate of 44 mSv was calculated in VARSKIN+ (using the 75th percentile of deposited volume and 25th percentile of injury depth data). This is approximately 10 % of the 500 mSv employee annual skin dose limit and 30 % of the 150 mSv skin dose at which classification is recommended [8]. Considering an average incidence of 3.7 needlestick injuries per 100 Healthcare Workers (HCWs) per year [7], the calculated doses suggest that employees handling Tc-99m are not likely to approach the dose limits due to the risk of NSI alone, especially if gloves are worn and decontamination is performed. However, this may not be true for other radiopharmaceuticals, particularly those with a longer effective half-life, higher activity concentrations and alternate decay schemes.

5. Method limitations

The findings of this experiment are applicable to needlestick injuries involving Tc-99m HMDP and 23G needles only. A study investigating the efficacy of skin surface decontamination found a significant difference in the mean remaining activity between different radiopharmaceuticals [34]. Another study found that needle bore size is a significant factor in fluid deposited in a needlestick injury [14].

Results are highly dependent on the material properties of the phantom. Mechanical and surface properties will affect the needle resistance, and absorptive properties will impact decontamination efficacy. The agar concentration was selected to have similar elasticity to the skin. However, a review of TMPs states that *'the applications of agar based skin models are diverse, but limited to noncontact or light contact'* [16]. Other phantom types may be more applicable to NSI.

The results have a wide range and are variable due to the technique of piercing by hand. This method was intended to be representative of the variation in force experienced in a real NSI. Future studies may wish to control the force of puncture with an automated lancet [30], which may enable a comparison between single and double glove layers.

Contamination monitor readings were a large source of uncertainty in activity measurement. For future investigations, a digital contamination monitor is recommended. Direct activity measurement with a gamma camera is preferable, availability permitting. Alternatively, a high precision balance (measuring tens of nanolitres) could be used to weigh the deposited volume. Balances are common instruments in Nuclear Medicine departments for Glomerular Filtration Rate (GFR) studies.

6. Conclusion & future work

Needlestick injuries involving Tc-99 m HMDP have been simulated by piercing agar test objects by hand. Deposited volume and injury depth data has been collected for the calculation of skin dose. The median deposited volume in a NSI was 100 ± 50 nl without gloves and 50

± 20 nl through one glove layer. The median injury depth was 4.0 ± 0.4 mm.

There was a 50 % reduction in the average volume deposited through a single glove layer compared to test objects pierced without gloves. Although not statistically significant, the result is promising. Results lie within the range of similar studies, some of which report significant reduction due to gloves [10–15]. The data for NSIs occurring through two gloves was highly variable due to the increased force required to puncture the double layer. Therefore, further work is required to evaluate the protection that gloves offer in the event of a NSI.

Skin doses have been estimated by inputting the median values of deposited volume and injury depth into VARSKIN+. For a NSI involving 1011 MBq/ml of Tc-99m HMDP the estimated SDE is 11 ± 5 mSv. A cautious dose estimate using the upper and lower quartiles of the datasets has been calculated at 44 mSv. These results do not account for decontamination, and use the larger value of volume deposited without gloves. It is thought that employees working with Tc-99 m alone are unlikely to approach dose limits due to the risk of NSI alone. However, the volume deposited may differ for other radiopharmaceuticals.

Rinsing the affected site for 60 s reduced the activity deposited by an average of 42 ± 6 %. Application of hand soap and decontamination agent did not reduce contamination further, however this is thought to be due to increased absorption time for these samples, indicating that decontamination measures should be carried out as soon as possible in the event of a NSI. It is thought that further reduction can be achieved by encouraging bleeding of the site.

It is acknowledged that there are limitations to the methods employed in this project. Further research is encouraged to build on the results presented here.

Funding

None.

Ethical approval

Not required.

Declaration of competing interest

None declared.

Acknowledgements

We would like to thank all who provided additional support and advice for this project, including David Hall, Colin Lee and Helen Coomber.

References

[1] J. Elliott, M. Weatherley, A case report of radiopharmaceutical needlestick injury with scintigraphic imaging and dose quantification, Radiol. Case Rep. 17 (5) (2022) 1718–1721, https://doi.org/10.1016/j.radcr.2022.02.055.
[2] J.C. Hung, S.J. Krause, C.L. Schmit, Sensible approaches to avoid needle stick accidents in nuclear medicine, J. Nucl. Med. Technol. 27 (4) (1999) 290–293.
[3] NHS England and NHS Improvement.Diagnostic imaging dataset annual statistical release 2019/20. England: The NHS, 2020, available at: https://www.england.nhs.uk/statistics/wp-content/uploads/sites/2/2020/10/Annual-Statistical-Release-2019-20-PDF-1.4MB.pdf [accessed 30 05 2024].
[4] A. Auta, E.O. Adewuyi, A. Tor-Anyiin, J.P. Edor, G.T. Kureh, V. Khanal, et al., Global prevalence of percutaneous injuries among healthcare workers: a systematic review and meta-analysis, Int. J. Epidemiol. 47 (6) (2018) 1972–1980, https://doi.org/10.1093/ije/dyy208.
[5] National Audit Office. A safer place to work: improving the management of health and safety risks to staff in NHS trusts, The Audit Office, London, 2003. ISBN: 102921431.
[6] B. Elmiyeh, I.S. Whitaker, M.J. James, C.A. Chahal, A. Galea, K. Alshafi, Needlestick injuries in the National Health Service: a culture of silence, J. R. Soc. Med. 97 (7) (2004) 326–327, https://doi.org/10.1177/014107680409700705.
[7] M.M. Elseviers, M. Arias-Guillén, A. Gorke, H.J. Arens, Sharps injuries amongst healthcare workers: review of incidence, transmissions and costs, J. Ren. Care 40 (3) (2014) 150–156, https://doi.org/10.1111/jorc.12050.
[8] The ionising radiation regulations 2017, Stat. 1075, 1 Jan 2018, available at: https://www.legislation.gov.uk/uksi/2017/1075/contents/ [accessed 09 01 2024].
[9] D.M. Hamby, C.D. Mangini, J.M. Luitjens, D.L. Boozer, Z.G. Tucker, C.T. Rose, et al.. (Renaissance Code Development, LLC Corvallis, Oregon), VARSKIN+ 1.0 a computer code for skin contamination and dosimetry assessments, Revision 4, U.S. NRC, 2021. Report number: NUREG/CR-6918.
[10] S.T. Mast, J.D. Woolwine, J.L. Gerberding, Efficacy of gloves in reducing blood volumes transferred during simulated needlestick injury, J. Infect. Dis. 168 (6) (1993) 1589–1592, https://doi.org/10.1093/infdis/168.6.1589.
[11] M.D. Gaughwin, E. Gowans, R. Ali, C. Burrell, Bloody needles: the volumes of blood transferred in simulations of needlestick injuries and shared use of syringes for injection of intravenous drugs, AIDS 5 (8) (1991) 1025–1027.
[12] S.U. Din, M.G. Tidley, Needlestick fluid transmission through surgical gloves of the same thickness, Occup. Med. 64 (1) (2014) 39–44, https://doi.org/10.1093/occmed/kqt135 (Lond).
[13] D.R. Lefebvre, L.F. Strande, C.W. Hewitt, An enzyme-mediated assay to quantify inoculation volume delivered by suture needlestick injury: two gloves are better than one, J. Am. Coll. Surg. 206 (1) (2008) 113–122, https://doi.org/10.1016/j.jamcollsurg.2007.06.282.
[14] R. Krikorian, A. Lozach-Perlant, A. Ferrier-Rembert, P. Hoerner, P. Sonntag, D. Garin, et al., Standardization of needlestick injury and evaluation of a novel virus-inhibiting protective glove, J. Hosp. Infect. 66 (4) (2007) 339–345, https://doi.org/10.1016/j.jhin.2007.05.008.
[15] N.T. Bennett, R.J. Howard, Quantity of blood inoculated in a needlestick injury from suture needles, J. Am. Coll. Surg. 178 (2) (1994) 107–110.
[16] A.K. Dąbrowska, G.M. Rotaru, S. Derler, F. Spano, M. Camenzind, S. Annaheim, et al., Materials used to simulate physical properties of human skin, Skin Res. Technol. 22 (1) (2016) 3–14, https://doi.org/10.1111/srt.12235.
[17] Y. Yang, L. Wang, F. Yan, X. Xiang, Y. Tang, L. Zhang, et al., Determination of normal skin elasticity by using real-time shear wave elastography, J. Ultrasound Med. 37 (11) (2018) 2507–2516, https://doi.org/10.1002/jum.14608.
[18] M. Wiertlewski, V. Hayward, Mechanical behavior of the fingertip in the range of frequencies and displacements relevant to touch, J. Biomech. 45 (11) (2012) 1869–1874, https://doi.org/10.1016/j.jbiomech.2012.05.045.
[19] U. Hamhaber, F.A. Grieshaber, J.H. Nagel, U. Klose, Comparison of quantitative shear wave MR-elastography with mechanical compression tests, Magn. Reson. Med. 49 (1) (2003) 71–77, https://doi.org/10.1002/mrm.10343.
[20] V.T. Nayar, J.D. Weiland, C.S. Nelson, A.M. Hodge, Elastic and viscoelastic characterization of agar, J. Mech. Behav. Biomed. Mater. 7 (2012) 60–68, https://doi.org/10.1016/j.jmbbm.2011.05.027.
[21] A. Irwin, C. Turner, R. Stewart, Report of the 2020 British Nuclear Medicine Society survey of nuclear medicine equipment, workforce and workload, Nucl. Med. Commun. 43 (6) (2022) 731–741, https://doi.org/10.1097/MNM.0000000000001561.
[22] Siemens Healthcare. Symbia intevo bold system specifications, Siemens Medical Solutions USA Inc., Malvern (PA), 2018.
[23] J. Alvarez, Development of a biokinetic model for radionuclide-contaminated wounds and procedures for their assessment, dosimetry and treatment, Health Phys. 95 (2) (2008) 258.
[24] Renaissance Code Development, VARSKIN+ v1.1 Software release note, Radiation protection computer code analysis and maintenance program (RAMP), 2022, available at: https://ramp.nrc-gateway.gov/sites/default/files/codes/varskin/documentation/release-notes/varskin-1.1-release-note.pdf [accessed 30 05 2024].
[25] ICRP, The 2007 Recommendations of the International Commission on Radiological Protection, ICRP Publication 103, Ann. ICRP 37 (2–4) (2007).
[26] Health Products Regulatory Authority, Summary of product characteristics: STAMICIS. UK: the authority, 2022, Document number: CRN00DR4J, available at: https://www.hpra.ie/img/uploaded/swedocuments/Licence_PA0677-018-001_08052024171729.pdf [accessed 30 05 2024].
[27] Health Products Regulatory Authority, Summary of product characteristics: OSTEOCIS. UK: the authority, 2020, Document number: CRN009NW0, available at: https://www.hpra.ie/img/uploaded/swedocuments/Licence_PA0677-007-001_21052020132036.pdf [accessed 30 05 2024].
[28] ICRP, Nuclear Decay Data for Dosimetric Calculations, ICRP Publication 107, Ann. ICRP 38 (3) (2008).
[29] IBM SPSS Statistics, https://www.ibm.com/products/spss-statistics [accessed 09 01 2024].
[30] A. Wittmann, N. Kralj, J. Köver, K. Gasthaus, H. Lerch, F. Hofmann, Comparison of 4 different types of surgical gloves used for preventing blood contact, Infect. Control Hosp. Epidemiol. 31 (5) (2010) 498–502, https://doi.org/10.1086/652158.
[31] ICRP, ICRP Statement on Tissue Reactions / Early and Late Effects of Radiation in Normal Tissues and Organs – Threshold Doses for Tissue Reactions in a Radiation Protection Context,ICRP Publication 118, Ann. ICRP 41 (1–2) (2012) 86–87.
[32] D. Delacroix, J. Guerre, P. Leblanc, C. Hickman, Radionuclide and radiation protection data handbook 2002, Radiat. Prot. Dosim. 98 (1) (2002) 1–168, https://doi.org/10.1093/oxfordjournals.rpd.a006705.
[33] V. Wyngaert, K. Strobel, W.U. Kampen, T. Kuwert, W. Bruggen, H.K. Mohan, et al., The EANM practice guidelines for bone scintigraphy, Eur. J. Nucl. Med. Mol. Imaging 43 (9) (2016) 1723–1738, https://doi.org/10.1007/s00259-016-3415-4.

[34] P. Covens, D. Berus, V. Caveliers, L. Struelens, D. Verellen, Skin contamination of nuclear medicine technologists: incidence, routes, dosimetry and decontamination, Nucl. Med. Commun. 33 (10) (2012) 1024–1031, https://doi.org/10.1097/MNM.0b013e32835674d9.

[35] E. Seymour, M. Talboys, W. Thomson, Case study: Radiopharmacy needle stick injury, IPEM RPA Update (2021), 24 June 2021.

[36] M.A. Bolzinger, C. Bolot, G. Galy, A. Chabanel, J. Pelletier, S. Briançon, Skin contamination by radiopharmaceuticals and decontamination strategies, Int. J. Pharm. 402 (1–2) (2010) 44–49, https://doi.org/10.1016/j.ijpharm.2010.09.027.