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SHORT COMMUNICATION

A comparison of two peak skin dose metrics calculated by patient dose management systems: implications for clinical management

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Objective: The patient dose monitoring systems DoseWatch and DoseWise were compared to evaluate their reported patient Peak Skin Dose.
Methods: 20 patients with the highest Peak Skin Dose on DoseWise were obtained; the values were converted to a Reference Point Air Kerma (RPAK) value and used for comparison. These patients were accessed in DoseWatch to obtain the recorded Worst Case RPAK. The co-ordinates for the position were obtained for each patient to find a primary and secondary angular position for the peak skin dose. The two positions produced by the two softwares were compared.
Results: There is a mean deviation of over 0.5 Gy between the two software packages when comparing the calculated maximum skin air kerma Peak skin dose from DoseWise and the Worst Case RPAK from DoseWatch.
Conclusion: We have shown mean deviations between these two systems. This difference is enough, for higher peak skin absorbed dose patients, to change the management of patients, so local services must understand their models to properly implement patient management.
Advances in knowledge: Neither system is incorrect, but these differences show that a deeper understanding of the analysis limitations is required to properly inform post-procedural high-skin dose follow-up procedures.

INTRODUCTION

X-ray-guided interventions in Cardiology and Radiology have produced many benefits in clinical practice allowing a more minimally invasive approach to be utilised. However, these procedures may, in certain types of procedure, have a risk of delivering skin dose levels high enough to produce deterministic effects.[1] In interventional cardiology, these effects are skin burns.[2] In the UK, patient radiation protection regulations[3] would expect, for those centres at risk of delivering such high skin doses to have in place 'High Dose Follow Up' procedures and also, where appropriate, to report such events to the appropriate regulator.[4]

The peak absorbed dose to skin is a single area of the skin that has received the highest absorbed dose (measured in Gy); the peak skin air kerma is the air kerma measured at the entrance surface of the patient (measured in Gy). Peak skin dose (PSD) is a term that is also used to refer to peak skin absorbed dose. One way to assess patient PSD is to utilise built-in analysis modules within Patient Dose Monitoring Systems (PDMS) that are both commercially and freely available. These systems calculate patient PSD from data held within the DICOM Radiation Dose Structured Report (RDSR)[5] files. These files contain enough information on the geometry and radiographic loading factors for each irradiation event to estimate the patient PSD. However, all systems use different models to estimate patient PSD and present the data in varying ways. The risk of a deterministic effect of the skin is related to the peak absorbed dose to the skin. However, not all models for the amount of radiation incident upon the skin include all the relevant factors to properly calculate the peak absorbed dose to the skin. In such cases, often peak skin air kerma is presented as a surrogate for peak absorbed dose to skin. Therefore, it is important for clinical users to understand the differences between these systems to ensure patient follow-up is managed appropriately. It is also important to appreciate that these systems were designed to provide post-procedural information and are very different from the skin dose systems provided by manufacturers of interventional

X-ray equipment that display some form of skin dose during the procedure to actively manage patient absorbed skin dose.

In this paper, we seek to compare results from two different PDMS (DoseWatch v. 2, GE Milwaukee and DoseWise v. 3, Philips Healthcare, Eindhoven) in how their peak skin dose metrics are calculated. DoseWatch v. 2 uses a sphere with a radius of 15 cm, centred at the isocentre as the patient surrogate and presents the PSD as an incident air kerma. DoseWise v. 3 uses a 'super ellipsoid' as the patient surrogate and presents the PSD as an absorbed dose to the skin. We show how an understanding of how the reported patient PSD is estimated is crucial in setting correct follow-up procedures for clinical care.

METHODS

From November 2019 to February 2020, 20 patients from the Trent Cardiac Centre at Nottingham University Hospitals NHS Trust with the highest absorbed dose to skin (called PSD) were obtained on DoseWise. These patients' records were then accessed in DoseWatch to obtain the recorded Worst Case Reference Point Air Kerma (RPAK) and the peak air kerma from a single 'cell' in the DoseWatch air kerma incidence map. This was performed by obtaining the patient's hospital ID from DoseWise and searching for the patient on DoseWatch. Both DoseWise and DoseWatch obtain the same event information from the same X-ray equipment for each patient thus the DICOM RDSR will be the same.

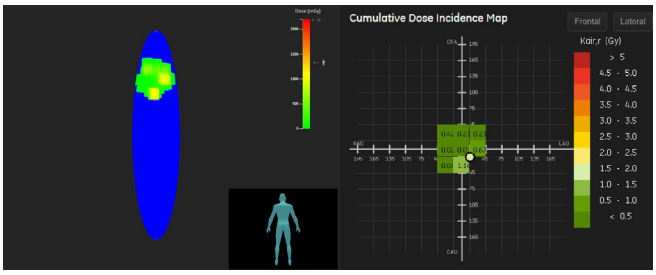
To compare the two softwares, the PSD from DoseWise was converted to an RPAK value; this was achieved by using the following equation:

$$RPAK = \frac{PSD \times Transmission\ percentage\ through\ the\ pad}{Backscatter\ factor \times F \times Table\ attenuation}$$

where the backscatter factor accounts for the scattered radiation absorbed by the skin, the F (F-factor) is a conversion factor between absorbed dose in air and skin, the table attenuation is the attenuation at 80 kVp X-rays through the table, and the transmission percentage through the pad is the amount of the beam that is not attenuated by the pad. These factors and values were provided on the individual patient event calculation report produced by DoseWise.

Note the table attenuation value that DoseWise calculates uses an average kV factor of 80kVp. We have found that the transmission factor ranges from 0.7 to 0.8 for kVp values of 120–55 respectively. This factor changes significantly at low kVp values, predominately below 65 kVp, but as the patients with a high PSD were imaged at 120 kVp we do not consider this a significant source of error.

Figure 1. Left – DoseWise, Right – cumulative dose incidence map on DoseWatch.



A Bland–Altman plot[6] was to be used for analysis to investigate the agreements between the two RPAK values; the Y-axis shows the differences between the two values and the X-axis represents the average of these values. The deviation of the measurements was obtained by subtracting the calculated DoseWise peak Air Kerma value from the DoseWatch RPAK value. The highest cell value in DoseWatch (from the cumulative dose incidence map mentioned below) was also obtained and compared to DoseWise's RPAK value in a Bland–Altman plot.

It was noted that the position of the maximum dose is displayed differently by the two software packages (Figure 1): DoseWatch displays a cumulative dose incidence map of Air Kerma for the exam as a function of gantry angle, averaged in 30 degree increments. The incidence calculations are made on the surface of a sphere 15 cm radius, centred on the isocentre, which is then projected on to a 2D map for display. The different squares/zones of the grid correspond to the angular increments. Adjacent squares are summed to indicate the maximum Air Kerma assuming beam overlap.

DoseWise displays the position of the peak absorbed dose to skin on a phantom. The position for each exposure the patient undergoes during the session is found on the individual patient event calculation report.

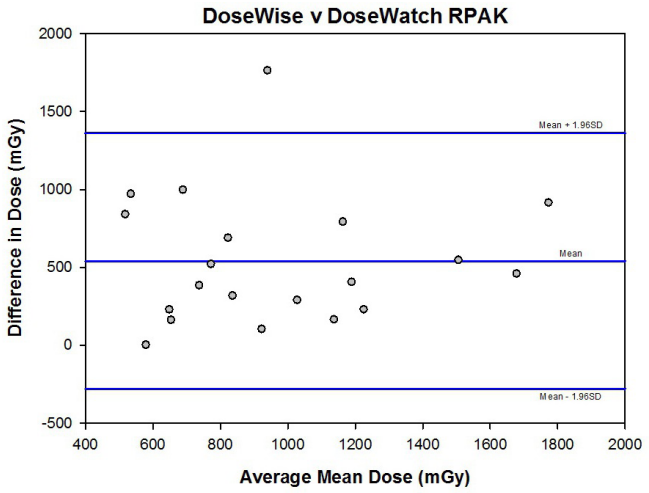
From each patient's event calculation report, the primary and secondary position angles were obtained for the event with the highest dose – this was taken to represent the position where the overall peak skin dose would be positioned on the patient.

From the cumulative dose incidence map (DoseWatch), the maximum Air Kerma, assuming beam overlap, is indicated by a colour-coded circle. The co-ordinates for this circle were obtained for each patient to find a primary and secondary angular position for the peak skin dose. The two positions produced by the two softwares were compared. As DoseWatch produces cells of 30° increments, each value had $a \pm 15°$ range added to it; from

Table 1. Maximum, median and minimum peak air kerma from DoseWise, and RPAK & max cell air kerma value from DoseWatch

	Peak air kerma from DoseWise (mGy)	RPAK from DoseWatch (mGy)	Max cell air kerma from DoseWatch (mGy)
Maximum	1400	2200	1800
Median	630	1200	890
Minimum	47	580	370

Figure 2. Bland–Altman plot of the RPAK value obtained from DoseWise and DoseWatch



this it was noted how many of the DoseWise values, for the 20 patients, would fit into the DoseWatch position range, to give a percentage of how many values correspond.

It was also investigated to see if the maximum Air Kerma was assumed to come from the cell with the highest value. The primary and secondary position angle was obtained from this cell by taking the centre value of the cell (*e.g.* if the cell begins at 15 and ends at 45, the angle is taken as 30). Once again, the percentage of DoseWise values that fell within the range of DoseWatch values were calculated.

The highest Peak Air Kerma calculated (DoseWise) and RPAK recorded (DoseWatch) during this time period were 1400 and 2200 mGy, respectively, and the lowest were 47 and 580 mGy. (Table 1)

Figure 3. Bland-Altman plot of the highest cell Air Kerma obtained from DoseWise and Dosewatch

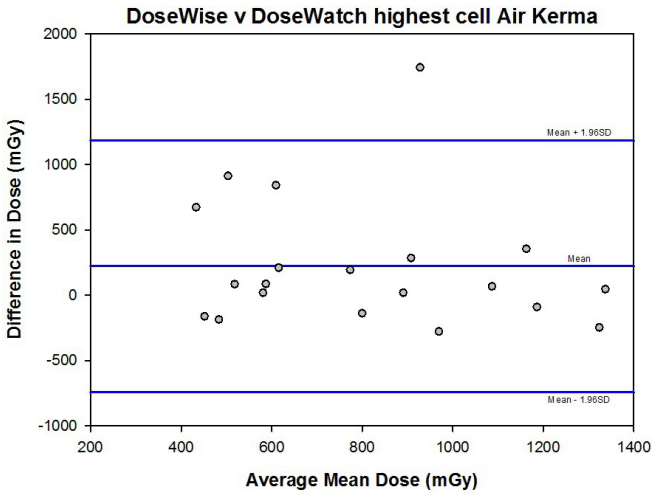
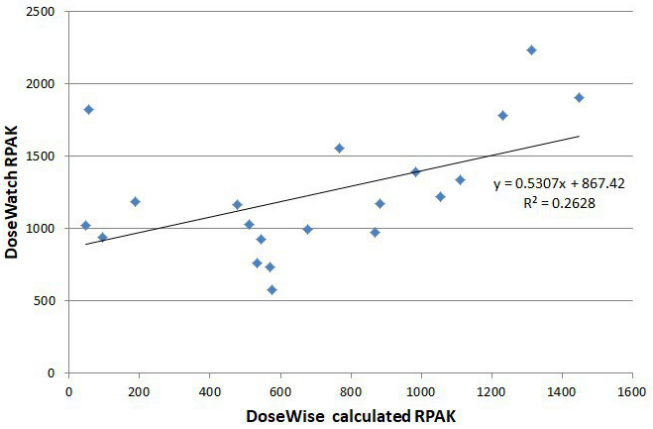


Figure 4. DoseWatch RPAK against DoseWise calculated RPAK



The Bland–Altman plot for the RPAK values demonstrates there is a mean deviation of 540 mGy of Air Kerma values between the two softwares. The limits of agreement are 1361 and −280 mGy (Figure 2)

The Bland–Altman plot for the highest cell Air Kerma values shows there is a mean deviation of 221 mGy of Air Kerma values between the two softwares. The limits of agreement are 1185 and −743 mGy (Figure 3).

A plot of the ratio of the DoseWatch RPAK and the DoseWise calculated RPAK was plotted against each other. It can be seen that there is no definite correlation between the two systems (Figure 4).

This plot however does not make clear what the relationship is between the two softwares. It could be interpreted that if the four points with the lowest RPAK calculated on DoseWise were omitted, then there would be a linear correlation; however if the three points with the highest RPAK were omitted, then it would give a correlation that DoseWatch remains constant as DoseWise increases.

The percentage of DoseWise angular positions within DoseWatch's value range can be seen in Table 2 for both the co-ordinates of the colour-coded circle and the central coordinates of the cell with the highest value for Air Kerma.

DISCUSSION & CONCLUSION

These results show a mean deviation for our small set of patients. This difference is enough, for higher peak skin absorbed dose patients, to change the management of patients so local services

Table 2. Percentage of DoseWise position values within DoseWatch's range for the primary and secondary angles

	Primary Angle	Secondary Angle
Circle co-ordinates	40%	10%
Highest cell	50%	30%

must understand their models to properly implement patient management.

It is important to understand these differences. In DoseWatch, the peak air kerma is shown in an incidence map made up of cells representing 30^0 ranges of both primary and secondary angulations centred on a [0^0, 0^0] angulation. A 'Worst Case RPAK' is demonstrated at the intersection of four cells that have the highest sum total of peak air kerma values. This is an attempt to allow for worst case beam overlap between cells and potentially will lead to an overestimate of peak air kerma, whereas taking the maximum cell value may result in an underestimate. Both systems reflect reality for the phantom that the software model uses and again will not reflect actual patient doses unless the patient skin surface coincides with that of the model's phantom.

Some interventional units have sophisticated 'skin dose' modelling built into the actual imaging equipment. In some instances, it may be that these 'in-lab' systems are more realistic than PDMS systems for the management of patient follow-up after high-dose procedures. Furthermore, these data are real-time and so provide for immediate decision-making.

The method for comparing the position of the peak 'dose' from both systems had some limitations. The DoseWatch position was assumed to either be at the centre of the four highest neighbouring cells or the centre of the highest cell. For DoseWise, it was assumed to lie at the centre of the highest 'dose' irradiation event. These approaches are unlikely to be correct in reality. However, the differences between the actual positions of the peak value of 'dose' are small on average but have some large variations between patients due to the nature of how this data is presented by the two systems. It is felt that, in practice, centres would advise the patient in a reasonably general way to look out for skin reddening, thus meaning precise values of angulations would not be helpful to a patient or clinician.

Both software packages provide useful information regarding patient skin dose from complex cardiological procedures and enable quantitative skin dose information to be assessed prior to determining whether or not a trigger for post-procedure high-skin dose follow-up is required. Furthermore, both packages have been validated.[7,8]

However, whether the model utilises absorbed dose to skin or peak skin air kerma, it is important that the user understands both the data and its limitations when utilising such data within clinical management procedures and useful information has been published in an EU-funded research project.[9] For instance, in our comparison one system presents data as absorbed dose to skin, whilst the other presents skin air kerma. Training in these systems, therefore, is vital to ensure correct interpretation of results. Such training must involve an understanding of the potential differences between actual patient peak absorbed dose to skin and the number presented by the software. This is provided by the evidence used by the suppliers for validation.

We have shown systematic differences between these two systems regarding skin dose information provided. We do not claim that either system is 'incorrect'. However, these differences show that a deeper understanding of the analysis limitations is required to properly inform post-procedural high-skin dose follow-up procedures.

REFERENCES

1. Vano E, Sanchez R, Fernandez JM, Gallego JJ, Verdu JF, de Garay MG, et al. Patient dose reference levels for interventional radiology: a national approach. *Cardiovasc Intervent Radiol* 2009; **32**: 19–24. doi: https://doi.org/10.1007/s00270-008-9439-9
2. Balter S, Hopewell JW, Miller DL, Wagner LK, Zelefsky MJ. Fluoroscopically guided interventional procedures: a review of radiation effects on patients' skin and hair. *Radiology* 2010; **254**: 326–41. doi: https://doi.org/10.1148/radiol.2542082312
3. The ionising radiation (medical exposure) regulations 2017 (statutory instruments No. 1322). London. 2017;.
4. Significant accidental and unintended exposures under IR(ME)R: Guidance for employers and duty-holders. *Care Quality Commission* 2019;.
5. http.. Available from: ://dicom.nema.org/dicom/2013/output/chtml/part16/sect_XRayRadiationDoseSRIODTemplates.html.
6. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet* 1986; **1**: 307–10.
7. Greffier J, Grussenmeyer-Mary N, Larbi A, Goupil J, Cayla G, Ledermann B, et al. Experimental evaluation of a radiation dose management system-integrated 3D skin dose map by comparison with XR-RV3 Gafchromic® films. *Phys Med* 2019; **66**: 77–87. doi: https://doi.org/10.1016/j.ejmp.2019.09.234
8. Lemieux B, Anaskevich L, Zhang J. Validation of DoseWise portal for peak skin dose estimation.In: *Proceedings of the AAPM 61st Annual Meeting & Exhibition* 2019;July 14-18th; San Antonio, Texas, United States of America; The American Association of Physicists in Medicine, 2019.
9. Dabin J, Deleu M, feghali J, Gallagher A, Maccia M, Malchair F, et al. Acceptance and quality control protocols for skin dose calculating software solutions in interventional cardiology [EJP-CONCERT Report D9.143. *2020 Eu Concert H* 2020;.