Correlation of peak skin dose with geometrical and dosimetric parameters from interventional procedures

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Aims and objectives

Interventional procedures are extensively used, nowadays, for diagnostic and therapeutic purposes. However, these procedures involve the inherent risk of excess use of radiation. The quantity that mostly concerns researchers lately is Peak Skin Dose (PSD), which is the maximum dose absorbed anywhere on the skin of the patient (1). Therefore, it is linked to the possibility of skin injury (2). As the complexity of the procedures increases, skin dose, and therefore the risk of serious skin injuries, increases as well. Peak skin dose is not easily measured during a procedure. The methods for direct measurement are complex and time consuming. Peak Skin Dose can also be calculated using related parameters like Dose Area Product (DAP) and Dose at Reference Point (RP). However, these indirect methods are not accurate and only provide an estimation of PSD. If the reference point is on the patient's skin and the beam does not move during the procedure, then the calculation of PSD is easy to be performed. In most cases though, the tube angles change throughout the procedure. This fact, complicates the PSD calculations but usually benefits the patient as the beam irradiates the body from a different direction and thus helps to reduce the maximum skin dose (3-5). The purpose of this study is to quantify this effect and particularly the reduction in skin dose when changing specific geometrical parameters, like the tube primary (lateral) and secondary (craniocaudal) angle.
Methods and materials

As a first step of this study, a non-patient experiment was performed. A mathematical phantom simulating the trunk of a reference patient (40 cm wide, 20 cm thick, 80 cm long) was considered to undergo four interventional procedures of ten fluoroscopy events each. The tube angle combinations (primary - secondary unique angle combinations) used at each intervention differed, while all the rest parameters remained constant (DAP, Dose at RP, irradiation field, table positioning). In order to consider an angle combination as unique, the primary or the secondary angle had to be at least 5° different from the other combinations. This was taken as a criterion because it was considered high enough to alter the irradiated area and low enough to avoid missing the area of interest. The first experiment was performed with the tube remaining still (one angle combination). The other three experiments involved two, three and five different angle combinations respectively (20, 30, 50 % Unique Angle Percentage). In particular, the primary angle was changed in the range 0° - ±40°. The size of the irradiation field was selected to be similar to the ones used in the most common procedures of the heart (e.g. cardiac catheterization). After each procedure, the effect of Unique Angle Percentage on PSD was tested.

After this initial experiment, the same study was performed using data from real interventions. The data used came from procedures that had been completed before the study was decided, in order not to bias the behavior of the physicians. The study was performed on 1833 cases coming from nine interventional rooms (3x Philips Allura XPer# 6x Siemens Axiom Artis) located in four different hospitals in two different countries. For the analysis of the data and PSD calculation, the patient radiation dose monitoring solution tqm|DOSE (QAELUM NV, Belgium) was used. tqm|DOSE has introduced a module that automatically collects all available geometrical and dosimetric data from the Radiation Dose Structured Report (RDSR), calculates the dose distribution on the patient's irradiated skin and provides a PSD map (Figure 1).
Fig. 1: The dose distribution map as presented by the tqm|DOSE radiation dose monitoring system. Each color corresponds to a specific dose range described in the legend. Besides the PSD, the areas that have received a dose of 90, 50 and 10% of the PSD value are also calculated, as well as the total area that has received a dose above zero.

References: QAELUM NV - Leuven/BE

It also performs an angle and table analysis, allowing for the calculation of the Unique Angle Percentage for each patient (Figure 2).
Fig. 2: The angle analysis chart presented in the tqm|DOSE radiation dose monitoring system. Each color corresponds to the frequency that the particular angle combination has been used, as described in the legend.

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Moreover, the areas that received a dose of 90%, 50% and 10% of the PSD value, as well as the Total Dose Area (area with doses above zero) were also calculated.
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Results

In the case of the non-patient-experiment, a linear reduction was observed when plotting the Unique Angle Percentage with the Dose Ratio of our interest (ratio of PSD to Dose at RP). As can be seen in the animated image, by changing the primary angle more times, the total irradiated area increases, while the PSD decreases (Figure 3). This is indicated in the animated image by observing the initial white square field (high dose) becoming grey (less dose), while the irradiated area is getting larger. Additionally, results were better when the different angles were used with uniform frequency throughout the procedure.

Fig. 3: The result of the non-patient experiment. The animated image shows successively the four procedures of different Unique Angle Percentages (1: using one tube angle combination, 2: using two tube angle combinations, 3: using three tube angle combinations, 4: using five tube angle combinations). The first image
(white square) corresponds to the case of the tube irradiating constantly on one direction. As more tube angle combinations are being used (Unique Angle Percentage increases), the irradiated area also increases, while PSD decreases. As can be seen, the initial white area that corresponds to high PSD (100% of Dose at RP) is turned into grey (60% of Dose at RP) in the case of 50% Unique Angle Percentages (five different primary angles used in the range 0 - +/-40 degrees). It is also noticed that the PSD area decreases as it is now limited to a few narrow grey columns, due to field overlapping.

References: QAELUM NV - Leuven/BE

The result of the first experiment was the reduction of PSD when changing frequently the tube angles. The next step was to study if the same outcome could be derived using the patient data. A typical example of the results is shown in Figure 4. In this particular procedure, at the beginning PSD is increasing together with Dose at RP. When the operator starts to change the angles, PSD stops increasing even though the irradiation continues.

References: QAELUM NV - Leuven/BE

This trend can be observed in almost all devices. Another important outcome of the analysis is that there are cases that the tube angles remain constant during the whole procedure. As expected, in these cases, the ratio of PSD to Dose at RP is close to unity.
PSD can even be higher than Dose at RP, since it includes backscatter radiation. This is more likely to happen when the patient is also positioned closer to the tube than RP. Moreover, the ratio of the area that received 90% of PSD to the Total Dose Area (area with doses above zero) was also calculated.

For the data analysis, only the interventions with more than 5 events were included, in order to obtain more correct percentages (a case with one or two events, will give a percentage of 50% or 100% which will lead to false results). Even though interventions from all procedures were analyzed, we took into consideration only the ones that included similar, relatively small, irradiation fields (mostly cardiac procedures), in order to decorrelate the dependence of the field. Moreover, there were procedures with very large fields that would overlap and then, counting angles of 5° difference would not really alter the irradiation area. The number of cases that were included in the study after the filtering was 1588. In Figure 5, the graph of Dose Ratio and Unique Angle Percentage is shown for all the devices.

![Fig. 5](image)

**Fig. 5**: Dose Ratio (PSD to Dose at RP ratio) is plotted against Unique Angle Percentage (Ratio of different angle combinations to the number of events) for all nine devices. A consistent trend can be observed. By changing the angles by 50%, the PSD can be reduced by 50%. Individual cases that do not follow the trend have been studied. Their behavior above or below the trend line is usually due to either larger/smaller irradiation fields or table positioning changes.

**References**: QAELUM NV - Leuven/BE
From the graph, it is shown that by using different angles in 50% of the radiation events, the physician can reduce PSD even by 50% compared to Dose at RP. To obtain a more clear view of the results, in Figure 6, the same chart for one of the devices is presented.

**Fig. 6**: Dose Ratio (PSD to Dose at RP ratio) is plotted against Unique Angle Percentage for one of the devices studied. Besides some individual cases, there is an apparent trend. In most of the cases, there is a large number of angles used that reaches 70%. Correspondingly, the PSD is reduced, with the Dose Ratio decreasing by almost 60%. The reduction cannot be attributed only to angle changes, but it can be explained by that in cases where the collimation is limited to small fields, and the table positioning is not dramatically changed.

**References**: QAELUM NV - Leuven/BE

A similar tendency, less strong, is shown when correlating the angular changes with the ratio of high skin dose area to the total irradiated area (Figure 7).
Fig. 7: The ratio of the area that has received 90% of PSD value to the total irradiated area is plotted against the Unique Angle Percentage. A similar trend is shown. The Area Ratio is decreasing when more angles are used.

References: QAELUM NV - Leuven/BE
**Fig. 3:** The result of the non-patient experiment. The animated image shows successively the four procedures of different Unique Angle Percentages (1: using one tube angle combination, 2: using two tube angle combinations, 3: using three tube angle combinations, 4: using five tube angle combinations). The first image (white square) corresponds to the case of the tube irradiating constantly on one direction. As more tube angle combinations are being used (Unique Angle Percentage increases), the irradiated area also increases, while PSD decreases. As can be seen, the initial white area that corresponds to high PSD (100% of Dose at RP) is turned into grey (60% of Dose at RP) in the case of 50% Unique Angle Percentages (five different primary angles used in the range 0 - +/-40 degrees). It is also noticed that the PSD area decreases as it is now limited to a few narrow grey columns, due to field overlapping.

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Fig. 4: The part of tqm|DOSE that presents the dose, angle and table analysis is shown. In this example, the table has been kept almost constant (bottom right chart). At some point in the procedure (at almost 10:00), PSD stops increasing (red line of top left chart), and thus, the ratio of PSD to Dose at RP starts decreasing (up right chart). At this particular time, the chart of angle analysis (bottom left) shows that primary and secondary angles change many times.

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Fig. 5: Dose Ratio (PSD to Dose at RP ratio) is plotted against Unique Angle Percentage (Ratio of different angle combinations to the number of events) for all nine devices. A consistent trend can be observed. By changing the angles by 50%, the PSD can be reduced by 50%. Individual cases that do not follow the trend have been studied. Their
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**Fig. 7:** The ratio of the area that has received 90% of PSD value to the total irradiated area is plotted against the Unique Angle Percentage. A similar trend is shown. The Area Ratio is decreasing when more angles are used.

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Conclusion

Peak skin dose can be significantly reduced when properly changing the tube angles, in order to avoid the constant irradiation of the same area. Unquestionably, other parameters, also play an important role in dose reduction. In particular, field collimation is of major importance in order to take advantage of the dose reduction by rotating the tube. Besides the other significant parameters, this study highlights the necessity to use the flexibility that the device offers, as far as the tube orientation is concerned. Physicians should take this fact into consideration and introduce it to their techniques, to the extent that this is possible. In any case, this should not be implemented just to reduce the dose at the expense of a proper procedure execution (6). So far, the calculation of PSD together with angle analysis is only available after the completion of the procedure. By using a patient radiation dose monitoring system, the operating physician can identify techniques that require corrective actions in order to ensure patient safety, especially when high skin doses could be expected.
References