Review of individual radiation exposure and the impact of real-time radiation information on an Interventional Radiology (IR) team using real-time individual dosimeters for the insertion of central venous catheters

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Aims and objectives

While central venous catheter (CVC) insertion accounts for a large proportion of many interventional radiology services, there remains a paucity of information regarding the radiation dose to the operator and team for such cases.

Radiation safety is of particular importance to the interventional radiology team as members are constantly exposed to varying degrees of radiation and unlike other radiological examinations, members of an IR team do not have the opportunity to leave the procedure room during the fluoroscopic procedures.

Another reason for the high radiation exposure to IR team members is the proximity of the operator to the radiation source and it may not always be practical to use protection screens. Compliance with the use of lead goggles is hampered by discomfort, more so during longer procedures.

Furthermore, the occasions when need for angled projections arises may incur greater scattered radiation exposure to staff compared to conventional PA or AP projections.

In our institution, thermoluminescent detectors (TLDs) placed beneath the lead apron are de facto as per statutory requirement. TLDs are unsatisfactory as a surrogate estimation of the absorbed dose to parts of the body that are not covered by the lead apron such as the face (in particular the lens of the eye) generally returning an underestimated value. Another limitation of the TLD is its threshold for reporting dose, which some studies have reported at 0.1 mSv and doses below this are deemed 0 mSv (1). A dose value of 0 mSv only suggests that there is no greater risk in the way the person is working. However, a potential drawback of constantly getting 0 mSv in consecutive readings may lull the operator into a false sense of low exposure when in actual fact the cumulative dose might be substantial. The false sense of safety might also cause one to lose the motivation to improve work practice to reduce one’s personal dose.

The DoseAware System (Philips, but developed by Unfors Instruments AB, Göteborg, Sweden) enables real-time display of radiation dose received on a screen so as to heighten the staff’s awareness of radiation exposure during a procedure. The system consists of a few dosimeters that detect radiation and stores details that can be downloaded to a computer via a docking system; a monitor that displays dose rate information; two software programs that enables analysis and compilations of the dose data.
Published literature suggest that real time radiation feedback raises radiation dose awareness, the insight of which assists in the adoption of practices associated with dose reduction to health care workers (2,3,4,5).

This study aims to investigate how through the use of a real time personal radiation dosimeter (PDM), real time radiation feedback can impact on the radiation dose received by members of an IR team. It also attempts to evaluate the effective whole body dose received Hp(10) by the team members through the same PDM.
Methods and materials

This is a retrospective study of the radiation doses received via a PDM by a radiologist, radiographer and nurse in 134 procedures from May 2012 to May 2013 in a tertiary women’s and children’s hospital. The CVC insertions included in this study consist of a tunneled CVC, non-tunneled CVC and peripherally inserted CVC (PICC). Port-a-caths were excluded as the numbers were too small (n = 2). 15 procedures were excluded because of inadequate documentation of screening time or radiation dose.

Of the remaining 117 procedures, there were 81 paediatric cases and 36 adult cases.

The radiologist wears two PDMs, one external and another internal to the lead apron. The PDM worn internally is taken to be the estimated effective whole body dose.

The radiographer and scrub nurse only wears a PDM external to the lead apron.

PDMs worn externally measure the scatter doses received.

The DoseAware System allows real time visualization of radiation dose rates and has been used in this study to collect the dose information. The hypothesis is that awareness of real time radiation exposure rates can lead to a decrease in the personal dose. For example, IR staff can be more aware of which position in the room that has a high dose rate and therefore avoid that "hot spot" or decrease time spent in that position. They can also be alerted to keep a safe distance from the radiation source and use available radiation protection screens and adjust them into an optimal position. When seeing high dose rates, the operators might collimate the beam, or refrain from exposing longer than necessary.

The specifications of the DoseAware states that the dosimeter will not be able to detect dose rates less than 40 µSv/h, although the original equipment manufacturer states that it starts to detect down to 20-30 µSv/h to guarantee its measurements from 40 µSv/h. Hence, DoseAware was recommended to be placed external to the lead apron and used as a gauge of scatter radiation. In our study, after having understood the limitations of the DoseAware's threshold dose, we have modified its use and placed it beneath the lead apron as so as to obtain an estimate of the effective whole body dose Hp(10).

Therefore, the effective dose Hp(10) obtained via the PDM is to be strictly regarded as an estimate only. In addition, a solitary under-lead PDM does not provide any information about eye dose.

In Europe, Hp(10) from the dosimeter worn on the anterior chest beneath protective garments is assumed to be a good estimate of the operator’s effective dose, and
was previously considered an adequate indicator of the health detriment from radiation exposure (6).

Our study does not follow the recommendations of National Council on Radiation Protection and Measurements (NCRP) of the United States of America in combining the Hp(10) values from both body and collar dosimeters to estimate effective dose.

The DoseAware System

The DoseAware System comprises of a group of personal dosimeters (PDMs), a base station, a cradle and two computer programs.

A PDM consists of four semiconductor detectors and gives a Hp(10)-value which is the dose equivalent at a depth of 10 mm in tissue. The PDM measures dose rate in the range 40 µSv/h-150 mSv/h with the accuracy of ±10 % and 150 mSv/h - 300 mSv/h with the accuracy of ±20 %. The dose range is 1 µSv-10 Sv. The dose information is sent wirelessly to the base station near with 1-second delay and the base station can communicate with the PDMs in a range of 10 meters. The base station receives the information that has been sent from the PDMs, and visualizes dose-rates in shapes of bars for maximum 8 PDMs at the same time. The bars can have three colors where green bars shows dose-rates # 0,2 mSv/h, orange bars # 2 mSv/h and red # 20 mSv/h. The base stations second function is to store the received dose information and work as a link between the PDMs and the computer (7).

The DoseAware System has two computer programs that can be used for analyzing the dose information. The DoseView is used when a PDM is placed in a cradle and connected to the computer. The program shows the dose history of that PDM, and the information can be shown as a dose graph or as a dose table. The dose history cannot be saved. In this study, the Dose Manager program has been used for analyzing the dose data. This program can handle dose history from several PDMs, and the dose history can be shown as a dose graph or as a dose table (7).

These results were sent to a physicist at weekly intervals.

Before the study began, the staff was briefed on the purpose of the study: what the DoseAware System was, how it worked and it was highlighted that the PDM should be placed external to the lead apron for the radiographer and the scrubbed nurse whereas for the radiologist it should be placed both external to and beneath the lead apron. The main objective was to compare the dose information when the staff was working as per normal, with the period when they were able to see their current dose rate.

There was only one doctor assuming the role of the radiologist throughout the year. In contrast, the roles of the radiographer and scrubbed nurse were rotated among the different radiographers and scrubbed nurses that had participated in this study.

The radiation protection equipment used included lead aprons, thyroid shields and lead goggles. No protection screens were utilised during CVC insertions.
Closed phase

During the first 6 months of the study, the staff wore the PDMs that were blinded to the base station, i.e. the staff could not see the dose rate in real time. The radiation doses were nevertheless registered and this period is also called the “closed phase”. The idea was that they would be working just like they normally do while the PDM recorded their dose exposure. The dose information from the base station was downloaded once a week and reviewed by a physicist.

Open phase

During the subsequent 6 months, the team members' real time radiation rates were displayed on the base station and the radiation doses were still recorded. This phase was termed as the "open phase". Upon seeing the high dose levels displayed, the radiographer will alert the rest of the team members so as to guide radiation safety behaviour. The collection of the protocols and the dose information in the base station were performed once a week and reviewed by a physicist.

Data analysis

The PDM doses of interest were extracted with an analyzing tool in the DoseManager program. When the dose history was shown as a dose graph, a selection was made for the time interval for a procedure of interest and the "Legend-button" provided a selection summary which gave information about the total dose, peak dose and the mean dose for all the PDMs of interest. The total dose for each person involved in a procedure and the dose from the reference PDM was noted and used for further analyses. The dose rates (total amount of scattered dose/fluoroscopy time) of each member and also between the closed and open phases were analysed with a generalised linear mixed model as the data does not follow a normal distribution.

3 procedures were excluded from the analyses as the values were larger than the mean + 3 standard deviations. 2 of these belonged to the radiographer for PICC insertion and 1 belonged to the scrubbed nurse for PICC insertion. Possible explanations for such high values may be due to incorrect placement of the PDM or accidental screening while in close proximity to the radiation source.
Images for this section:

**Fig. 1:** DoseAware system

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**Fig. 2:** DoseManager

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Results

There is no significant difference in each member's dose rate between the open and closed phases.

An in depth analysis of the differences in the radiation dose between the closed and open phases for each type of CVC insertion does not yield any significant finding.

The radiologist receives the highest dose rate in the team (p <0.05). The radiologist's dose rate is 84% higher than the radiographer's and is 66% higher than scrub nurse's (p < 0.005).

Team members receive significantly higher dose rates (256% higher) for tunneled central venous catheter placement than for PICC placement (p <0.05).

The dose rate of the non-tunneled central venous catheter insertion is 36% lower than PICC insertion but is not significant (p = 0.241).

The mean effective whole body dose received by the radiologist for placements of a tunneled CVC, non-tunneled CVC and PICC are 0.638 µSv, 0.499 µSv and 0.398 µSv respectively.

The median dose for all 3 procedures were 0 mSv each.

The cumulative annual dose for CVC insertions is 0.0519 mSv.
Fixed Effects (May 2012 to May 2013)

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Probability distribution: Gamma
Link function: Log

**Fig. 4:** The radiologist receives the highest dose rate in the team (p < 0.05). Team members receive significantly higher dose rates for tunneled central venous catheter placement than for PICC placement (p < 0.05).

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Fixed Coefficients (May 2012 to May 2013)

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Probability distribution: Gamma
Link function: Log
**Fig. 5:** The radiologist receives the highest dose rate in the team (p < 0.05). Team members receive significantly higher dose rates for tunneled central venous catheter placement than for PICC placement (p < 0.05).

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**Fixed Coefficients (November 2012 to May 2013)**

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Probability distribution: Gamma
Link function: Log

**Fig. 3:** No significant difference in each member’s dose rate between the open and closed phases.

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**Fig. 7:** Team members receive significantly higher dose rates for tunneled central venous catheter placement than for PICC placement (p < 0.05).
Fig. 6: The radiologist receives the highest dose rate in the team (p <0.05).
Conclusion

A lack of significant difference in reduction of radiation dose from closed phase to the open phase of each IR team member for all CVC insertions may be attributed to the study design in which the radiation monitor faces the radiographer and the onus lies with the radiographer to inform the rest of the team members whenever a high dose rate is displayed, compared to other studies where all team members are able to view the real time dose rates themselves.

The proportion of adults and paediatric cases for the closed and open phases are relatively similar and thus any differences in patient's age are unlikely to confound our results.

An in depth analysis of any difference in the radiation dose between the closed and open phases for each type of CVC insertion does not yield any significant finding, and this may be attributed by the small sample size for each CVC insertion type (n < 10).

Our results confirm the hypothesis that the operator receives the highest scatter radiation dose amongst the IR team. It is of importance that the operator adequately protects himself much more than the radiographer and scrubbed nurse. The radiologist's dose rate received is 84% higher than the radiographer's and 66% higher than scrubbed nurse's (p<0.05). This is likely explained by the radiologist's close proximity to the scatter radiation source while the scrubbed nurse and radiographer stands at increasingly further distances from the radiation source.

Given that the team members received significantly higher doses and dose rates for the tunneled CVCs, more attention should be paid to dose reduction behaviour during such procedures such as minimising fluoroscopy time, the use of collimation and positioning themselves in low scatter areas.

The mean effective whole body dose received by the radiologist for placements of a tunneled CVC, non-tunneled CVC and PICC are 0.638 µSv, 0.499 µSv and 0.398 µSv respectively. On comparison with the ambient background radiation e.g. in Singapore which is about 0.1 µSv/h, or about 880 µSv per year (8), it can be shown that radiation dose for each tunneled CVC, non-tunneled CVC and PICC insertion is less than 0.1% of ambient background radiation.

The median dose for all 3 procedures were 0 mSv each, suggesting that at least half of the time during CVC insertion, the radiologist receives a negligible radiation dose.

In light that the radiologist's cumulative annual dose for CVC insertions is 0.0519 mSv (5.90% of ambient background radiation) and the median dose is 0 mSv for the CVC
insertions studied, it can be inferred that the radiation dose to the radiologist is small or negligible. Furthermore, since the scatter radiation dose rate received by the radiographer and scrubbed nurse are significantly lesser than that of the radiologist, the inference of a small or negligible radiation dose applies even more so for allied interventional radiology members in CVC insertions.

This raises the possibility of reducing or obviating the need of radiation protection equipment in allied interventional radiology members during CVC insertions while maintaining judicious dose reduction behaviours. For example, the radiographer could do away with a thyroid shield while standing behind a protection screen. Further prospective multi centre trials can be carried out to verify this finding.

On a separate note, the effective dose $Hp(10)$ obtained via the PDM is to be strictly regarded as an estimate only. In addition, a single under-lead PDM does not provide any information about eye dose. Future studies could be designed to include measurement of the equivalent dose of the neck, lens and hand as they will give more accurate estimates of these reference body parts. Furthermore, adoption of the recommendations of National Council on Radiation Protection and Measurements (NCRP) of the United States of America in combining the $Hp(10)$ values from both body and collar dosimeters to estimate effective dose could yield different results.

The ambient background radiation in Singapore is around 0.1 $\mu$Sv/h whereas the detection threshold of PDM is 40 $\mu$Sv/h, which is about 400 times the ambient background radiation. Thus, the ambient background radiation does not have any influence on the PDM readings.

In all, real time radiation feedback has not shown to be beneficial in dose reduction to IR members but this may be related to inherent differences in the study design compared to other studies. The low or negligible estimate dose of CVC insertions may possibly suggest doing away with or reducing the amount of radiation protection equipment in allied IR members. However, further prospective multicentre studies with detailed evaluation of the equivalent dose to the neck, lens and hand should be carried out to confirm our findings.
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