Evaluation of radiation exposure in central venous catheter (CVC) placement in paediatric patients using two fluoroscopy protocols on a flat-panel system

Poster No.: B-0218
Congress: ECR 2017
Type: Scientific Paper
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Keywords: Radioprotection / Radiation dose, Paediatric, Interventional vascular, Fluoroscopy, Venous access, Radiation safety, Dosimetry, Dosimetric comparison
DOI: 10.1594/ecr2017/B-0218

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Purpose

Central venous access plays an important role in the management of critically ill paediatric patients and those with difficult vascular access requiring antibiotic therapy, chemotherapy and haemodyalisis [1]. Safe and correct placement of such catheters requires fluoroscopic guidance [2-8]. Children pose different radiation dose related issues when compared to adult patients for various reasons. These issues are of relevance to both the patient and the primary operator. Children are more sensitive to radiation than adults and have a longer life after exposure during which they can manifest the deleterious effects of radiation. They are likely to require follow up for their primary condition and therefore repeated radiation exposure. The discrepancy between the patient and image intensifier size, results in larger portions of the child's body to be exposed. Gaining access in small paediatric patients requires the primary operator to be physically close to, and sometimes even enter the radiation beam, resulting in increased operator doses [9]. It is therefore important that paediatric interventional radiologists are aware of the radiation doses incurred in performing these procedures and of practices that allow for dose reduction while maintaining adequate image quality for clinical success.

The purpose of our study was to evaluate the patient and operator doses when using two different fluoroscopic protocols on a flat-panel digital system (FPDS) during central venous catheter (CVC) insertion.
Methods and materials

In this study we retrospectively analysed all central venous catheters inserted in our interventional radiology department. All aspects of our study were approved by the institutional review board at our hospital and informed consent was waived. Written informed consent was obtained for every procedure from child's parent/s or legal guardian prior to the procedure.

Patient population

Between July 2010 and September 2016, 110 consecutive image-guided CVCs were placed in 62 paediatric patients in our centre. The indications included measurement of haemodynamic variables, delivery of medications and nutritional support, and repositioning when exit site infection or catheter-related bloodstream infection was suspected. In the latter scenarios, a new site of insertion was always preferred.

Angiographic equipment

This study was completed in an angiographic suite using a FPDS. Phantom measurements were first performed using a TOR CDR phantom of 20 cm thickness, with the table placed at 75 cm from the radiation source, and a source to image-receptor distance (SID) of 100 cm and with a field of view (FOV) of 40 cm. 7.5 images per second were acquired for a total of 15 s, in both acquisition protocols (FP50 and FP35).

62 CVCs were placed using a fluoroscopic protocol that uses 50% of the nominal dose (FP50) whereas 58 CVCs were placed using a second fluoroscopic protocol that uses 35% of the nominal dose (FP35), with technical parameters adjusted for paediatric protocol.

The pulse mode was used for fluoroscopy in both protocols using 7.5 images/second. The automatic exposure control system, that determines automatically the optimal technique parameters such as kV, mAs, focal spot size and spectral filtration, was used in both protocols. Dose area product (DAP) and fluoroscopy time (FT) were measured with a dual-channel DAP/Dose meter transmission ion chamber fixed to the collimator with a valid calibration and quality control certificate validated every 6 months.

In addition, between October 2015 and September 2016, radiation dose to the primary operator, anaesthesia nurse and radiographer were recorded using electronic personal dosimeters placed on top of the lead apron at the level of the left anterior chest wall. Effective operator dose was calculated for the procedures performed in this time interval.
Interventional procedure

All CVC insertion procedures were carried out by two interventional radiologists with 13 and 10 years experience. Procedures were performed under general anaesthesia, according to American Society of Anaesthesiologists guidelines [10]. A control supine anteroposterior chest fluoroscopic image was acquired in the interventional radiology suite prior to starting the procedure. The right internal jugular vein was the preferred access site in all cases. Internal jugular venous puncture was always performed using US guidance [11]. Venous access was performed with a 21-gauge single-wall needle, 2.5 cm in length. A standard J-tip wire (or alternatively a 0.018-inch in patients with a small internal jugular vein of less than 5 mm) was inserted through the needle into the superior vena cava. Fluoroscopic guidance was then used to position the wire into the inferior vena cava and to evaluate the position of the catheter and catheter tip, which was usually placed at the cavoatrial junction. No angulation of the C-arm was performed. A final supine anteroposterior chest fluoroscopic image was acquired at the end of every procedure to document catheter position and to detect signs of pneumothorax. In the absence of valid clinical indications, no routine post-procedural chest X-Ray was performed [12]. A blood sample for haemoglobin level was taken 4 hours after every procedure to assess for bleeding complications.

Standard dose reduction measures routinely employed during the procedures include: adequate collimation limited only to the area of interest, a low object-to-detector and source-to-image distance, the "last image hold" feature, which displays the last active fluoroscopic image enabling image-review without additional fluoroscopic exposure. The DAP and fluoroscopy time values were archived into our Picture Archiving and Communications System (PACS) at the end of every procedure. For non-tunneled CVC, the typical catheter size varied from 4 Fr to 5.5 Fr, and double or triple lumen catheters were used. For tunneled catheters the 4.2 Fr or 5.5 Fr single lumen catheters were used.

Fluoroscopy protocol, DAP and fluoroscopy times were collected from PACS. The fluoroscopy times of each interventional procedure was recorded in seconds. DAP in cGy-cm², was also recorded and was considered a surrogate measurement of the entire amount of energy delivered to the child by the radiation beam during the procedure.

Image quality was retrospectively assessed by an independant interventional radiologist, who blindly reviewed procedural images in the PACS system, and graded imaging into 3 grades, Grade I being inadequate for a successful procedural outcome, Grade II being adequate with average image quality and Grade III being adequate with excellent image quality.

Statistical analysis:
Data collected was recorded using Excel 2007. To render the two groups comparable, DAP was normalized per unit of fluoroscopy time by dividing DAP by the fluoroscopy time (nDAP [cGy.cm²/s]). For each of the two patient groups, descriptive statistical analysis was used for analysis of the distribution of DAP and fluoroscopy time, expressed as the mean value ± SD, median and range. The nDAP and fluoroscopy time differences for each patient group were compared using the Student t test. Statistical results were considered significant when a p value of less than 0.05 was reached.
Results

During phantom studies, the percentage decrease in DAP between the FP50 and FP35 protocols at the parameters described above for a fluoroscopic exposure duration of 15 seconds, was 49.6%.

**Fig. 1**: Histogram demonstrating the difference in nDAP between the two different fluoroscopic protocols during the phantom studies performed.

**References**: Radiology Unit, IRCCS - ISMETT

Table 1 summarises patients' age, mass and nDAP of the two study groups. No statistically significant difference was found between the mean age (p = 0.12) and weight of the two groups (p = 0.13). The difference between the mean nDAP of the two groups was found to be statistically significant with a p value of 0.004 (unpaired t-test) with a 95% confidence interval. In the FP50 group, magnification was used in 20% of patients (FOV 32: 15% [n=9] and FOV 20: 5% [n=3]). In the FP35 group, magnification was used in 15% of patients (FOV 32: 10% [n=5] and FOV 20: 5% [n=2]).
Table 1: Age (months), Mass (kg) and DAP normalised for fluoroscopic time (nDAP; cGy.cm\textit{2}.s) for number of procedures (n) carried out using each fluoroscopic protocol. P value for means of both groups also included. Note: A nDAP value of 0 does not imply no dose delivered to the patient. It implies that the dose is too low to be detected by the DAP meter.

References: Radiology Unit, IRCCS - ISMETT

Data for tunnelled and non-tunnelled procedures was also compared and results are shown in Table 2. A statistically significant difference was noted between mean DAP for procedures using the FP50 protocol as compared to that using the FP35 protocol, in both tunnelled and non-tunnelled catheter insertions. This was not at the expense of increased fluoroscopic time, as demonstrated by the difference in fluoroscopy time of the two groups not being statistically significant.
Table 2: Dose area product (DAP; mean±standard deviation) and Fluoroscopic time (s; mean±standard deviation) differences for each type of catheter between the two protocols using unpaired t-test for 110 central venous catheters inserted.

References: Radiology Unit, IRCCS - ISMETT

For 18 CVCs inserted (4 tunnelled and 14 non-tunnelled) mean dose received by interventional radiologist was 0.04±0.07 µSv (range: 0-0.24 µSv, median: 0 µSv), that received by the radiographer was 0±0.01 µSv (range: 0-0.03 µSv, median: 0 µSv), while mean dose received by the anaesthesia nurse was 0.01±0.01 µSv (range: 0-0.03 µSv, median: 0 µSv). Table 3 summarises these results.

<table>
<thead>
<tr>
<th>Effective Dose (µSv)</th>
<th>Mean±SD</th>
<th>Median</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary Operator</td>
<td>0.04±0.07</td>
<td>0</td>
<td>0-0.24</td>
</tr>
<tr>
<td>Radiographer</td>
<td>0±0.01</td>
<td>0</td>
<td>0-0.03</td>
</tr>
<tr>
<td>Anaesthesia Nurse</td>
<td>0±0.01</td>
<td>0</td>
<td>0-0.03</td>
</tr>
</tbody>
</table>

Table 3: Effective Dose to the different operators involved in CVC placement. Note: A effective dose value of 0 does not imply no dose received by to the patient. It implies that the dose was low to be detected by the electronic personal dosimeter.

References: Radiology Unit, IRCCS - ISMETT

Image quality in all procedures carried out with the lower nominal dose protocol was considered adequate by an independent interventional radiologist (Grade 2: 47.6% and Grade 3: 52.4%). All these procedures were completed without the need to change to the higher nominal dose protocol.
Fig. 1: Histogram demonstrating the difference in nDAP between the two different fluoroscopic protocols during the phantom studies performed.

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Fig. 2: Image obtained post-insertion of a right-sided tunnelled CVC in a 4 month old infant using the lower dose protocol, FP35. Image quality is considered satisfactory for correct placement of the central catheter, with the catheter tip being readily identified on this projection.

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Conclusion

Novel technology allows for higher image quality at lower patient doses, decreasing radiation dose in fluoroscopically guided procedures such as CVC insertion, to patients and operators. Knowledge of interventional suite equipment and awareness of radiation protection help reach this aim.
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