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Radiation exposure and safety practices during pediatric central line placement

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Abstract

Purpose—Pediatric surgeons routinely use fluoroscopy for central venous line (CVL) placement. We examined radiation safety practices and patient/surgeon exposure during fluoroscopic CVL.

Methods—Fluoroscopic CVL procedures performed by 11 pediatric surgeons in 2012 were reviewed. Fluoroscopic time (FT), patient exposure (mGy), and procedural data were collected. Anthropomorphic phantom simulations were used to calculate scatter and dose (mSv). Surgeons were surveyed regarding safety practices.

Results—386 procedures were reviewed. Median FT was 12.8 seconds. Median patient estimated effective dose was 0.13 mSv. Median annual FT per surgeon was 15.4 minutes. Simulations showed no significant difference ($p = 0.14$) between reported exposures (median 3.5 mGy/min) and the modeled regression exposures from the C-arm default mode (median 3.4 mGy/min). Median calculated surgeon exposure was 1.5 mGy/year. Eight of 11 surgeons responded to the survey. Only three reported 100% lead protection and frequent dosimeter use.

Conclusion—We found non-standard radiation training, safety practices, and dose monitoring for the 11 surgeons. Based on simulations, the C-arm default setting was typically used instead of low dose. While most CVL procedures have low patient/surgeon doses, every effort should be used to minimize patient and occupational exposure, suggesting the need for formal hands-on training for non-radiologist providers using fluoroscopy.

Keywords

Radiation Dose; Fluoroscopy; Pediatric; Occupational Exposure

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The use of central venous access is a standard of care in the treatment of children across numerous disciplines. Children requiring chemotherapy, hemodialysis, parenteral nutrition, organ transplant anti-rejection therapy, and repeated phlebotomy, as well as patients with inadequate and unreliable peripheral venous access benefit from placement of central venous lines (CVL).¹ Pediatric surgeons routinely use fluoroscopic guidance for proper CVL placement. However, these procedures are not typically performed in an interventional suite optimized for radiological procedures. Most physicians using fluoroscopy outside the imaging department have minimal to no training in radiological protection [1]. We noted in our own institution a large variability in dosimeter use and lead protection between surgeons. It has been assumed that exposure to the operating surgeon and patient is insignificant during CVL placement [2]; however, this has not been established and has potential unforeseen consequences.

While prior publications have reported doses in adult venous access procedures [3], only estimated effective doses have been reported in pediatric CVL [4]. These investigations were performed by radiologists in an interventional suite. Operator and patient exposure for pediatric CVL placement performed outside of an interventional radiology suite has not previously been reported. Here we examine the intraoperative fluoroscopy use, safety practices, patient entrance exposure, estimated surgeon exposure, and estimated patient effective doses at a single institution during the placement of CVL performed outside of the radiology department.

1. Methods

Approval was obtained from the local institutional review board for this retrospective study (study number 042013-063). All fluoroscopically guided central venous access procedures performed on pediatric patients by 11 surgeons at a single institution over the calendar year 2012 were analyzed through query of the electronic medical record system. All surgeons had completed a formal pediatric surgery fellowship and had been staff physicians for longer than 1 year at the time of the study. Patients with CVL procedures performed by other non-surgeon providers or without fluoroscopic guidance were excluded. The patients' ages, number of devices placed, total fluoroscopic times (FT), and reference point air kerma ($K_{a,r}$) measured in milligrays (mGy) were collected. $K_{a,r}$ is an estimate of entrance exposure measured at a standard point from the C-arm radiation source [5] (model GE OEC 9800). The $K_{a,r}$ is only an estimate and does not account for positioning, backscatter, or body habitus. The patient effective dose is the sum of the products of the equivalent dose to each organ or tissue and represents whole body exposure; it is measured in sieverts (Sv) [6].

In order to estimate the patient effective dose and the surgeon scatter, simulations were performed using anthropomorphic thorax phantoms (Fig. 1) with real time measurement of modeled patient and surgeon skin exposure using an Unfors Patient Skin Dosimeter (LACO,

¹The following abbreviations are used in this article. ALARA: as low as reasonably achievable; CT: computed tomography; CVL: central venous line; DDE: deep dose equivalent; ECMO: extracorporeal membrane oxygenation; FT: fluoroscopic time; Gy: gray; ICRP: International Commission on Radiological Protection; IQR: interquartile range; $K_{a,r}$: reference point air kerma; LDE: lens dose equivalent; M: minimum; μ Gy: microgray; mGy: milligray; mrem: millirem; mSv: millisieverts; SDE: shallow dose equivalent; rem: roentgen equivalent in man; Sv: sieverts.

Inc.). The skin dosimeter probes were placed in the center of the field at the exposed surface of the model and at the thyroid level of a theoretical surgeon (Fig. 1). ATOM models 007TE-11 through 007TE-16 (CIRS, Inc.) tissue equivalent phantoms of the thorax were used for the following patient ages: newborn and 5, 10, 15, and 20 years. The simulations were performed with the C-arm (GE OEC 9900) in both default and low dose mode; collimation, magnification, and patient positioning were consistent with the standard operative practice. Level 1 magnification was used only for the newborn; the other ages were not magnified. The modeled surgeon position at the bedside did not change; however, the distance from the patient ranged from 42 to 45 cm depending on the phantom size. Positioning was consistent with surgeon practice. CVL placement was modeled for each phantom age and repeated three-fold to obtain an average entrance exposure (mGy/minute) and scatter exposure (mGy/minute) for that age group. Regression models of scatter based on age, FT, and C-arm mode were created from this data. PCXMC, a Monte Carlo based program that calculates patient doses from medical x-ray examinations, was used to estimate the effective dose from the phantom data. Patients were grouped by age: newborn to 9 months, 9 months to 3 years, 3 to 7.5 years, 7.5 to 12.5 years, 12.5 to 17.5 years, and 17.5 to 22 years; FT was used to calculate surgeon scatter and patient effective dose based on the respective phantom ages: newborn and 1, 5, 10, 15, and 20 years.

Surgeons were invited to complete a survey regarding their use of radiation safety. The survey questioned the percentage and type of radiation protection used, percentage of dosimeter use, and prior formal radiation safety training. All surgeons at the institution are required to complete an annual on-line radiation safety course. Formal training was considered any training with a classroom or hands-on component. The dosimeter reports over the calendar year 2012 corresponding with the procedural data were collected. Statistical analyses were performed with Microsoft's Excel® and Systat's Sigma Plot® for regression analyses as well as Student's t-test, Mann-Whitney, ANOVA, and ANOVA on ranks where applicable.

2. Results

386 CVL procedures were reviewed on 325 patients of whom 46 had repeat procedures. Patient ages ranged from newborn to 22 years. The median patient age was 4 years (8 months, 11 years [IQR]). Of these cases, 18% had incomplete $K_{a,r}$ exposure data; however, all FT data were collected. FT per procedure ranged from less than 1 second to 8.1 minutes with a median of 12.8 seconds (5.5, 29.5 seconds [IQR]). The range of entrance exposure per procedure was 12 μ Gy to 37.9 mGy with a median of 0.72 mGy (0.32, 2.12 mGy [IQR]). The range of calculated effective dose per procedure was 0.5 μ Sv to 5.5 mSv with a median of 0.13 mSv (0.06 mSv, 0.29 mSv [IQR]). The majority of lines were placed in the neck or chest; 25 procedures used an infra-inguinal approach to central access.

Entrance exposure varied significantly by the type of CVL. Port insertion was the most commonly performed procedure. Excluding a few rare cases of fluoroscopic use during cannula placement for extracorporeal membrane oxygenation (ECMO), tunneled hemodialysis insertion had the longest time and greatest median patient exposure (Table 1).

The median number of CVL procedures per surgeon in 2012 was 39 (15, 51 procedures [IQR]), with a range of 5 to 71 procedures. The cumulative FT per surgeon ranged from 1.8 to 37.7 minutes with a median of 15.4 minutes (10.5, 26.4 minutes [IQR]). The median procedure times and exposure per surgeon are reported in Table 2. There was an inverse correlation ($r^2 = 0.54$) with the surgeon's median FT per procedure and the total number of cases performed by that surgeon in 2012.

Phantom simulations showed no significant difference ($p = 0.14$) between the recorded $K_{a,r}$ (median 3.5 mGy/minute) and entrance exposure calculated with the modeled regression from the C-arm default mode (median 3.4 mGy/minute); a significant difference was found ($p < 0.0001$) from the low dose mode regression (median 1.8 mGy/minute). Based on these findings, the default mode was used to calculate the patient effective dose and surgeon exposure using age and fluoroscopic time. The calculated median yearly surgeon entrance exposure from scatter during CVL placement was 1.5 mGy (1.2, 2.4 mGy [IQR]) with a maximum of 3.3 mGy (Table 2).

Eight of the 11 surgeons responded to our radiation safety questionnaire (Table 3). All reported close proximity to the patient (directly at the bedside) for 100% of the procedures, regardless of trainee assistance. No one reported the use of leaded eyewear. Three surgeons reported 100% use of lead vest, apron, and thyroid shields. The remaining surgeons used a combination of incomplete protection. Two surgeons reported prior formal radiation safety training; however, this training was over 20 years ago in both instances. Three surgeons reported no radiation safety badge use. Surgeon yearly dosimetry recordings are reported in Table 2.

3. Discussion

Our investigation examined the ionizing radiation exposure to patients and surgeons as well as radiation safety practices during pediatric fluoroscopic CVL placement. We found that the majority of CVL procedures reviewed had low patient exposure with an FT of less than 15 seconds, entrance exposures less than 1 mGy, and a median patient effective dose of 0.13 mSv. One mGy is the equivalent of 10 chest x-rays in an adult or 17 in a newborn [6]. There was one case that extended beyond 8 minutes of FT with an entrance exposure of 37.9 mGy and an effective dose of 5.5 mSv. The published threshold for the deterministic effect of skin changes from ionizing radiation is greater than 2 Gy [7]. The doses from this study of CVL procedures are well below this limit; however, it is important to keep in mind the number of procedures and other diagnostic imaging that expose patients to additional ionizing radiation. Some patients have numerous procedures for venous access.

The stochastic risks, such as malignancy, from medical imaging are still not fully understood. The majority of epidemiologic studies identifying the consequences of ionizing radiation are derived from the Japanese atomic bomb survivors, a population that was instantaneously exposed to an average effective dose of 200 mSv [8]. The Life Span Study, a cohort of 105,427 Hiroshima and Nagasaki atomic bomb survivors, found an excess absolute risk of solid cancer increased throughout life at all ages. There was a significant radiation-associated increase in the risk of cancer in adolescence and young adults [9]. It is

not known if radiation risks at low doses can be extrapolated from atomic bomb survivors given the difference in dose and rate [8]. A recent retrospective cohort study from the U.K. found a relative risk of 3.18 for leukemia in children who received a bone-marrow-absorbed dose of at least 30 mGy from CT scans and a relative risk of 2.82 for brain cancer with a brain-absorbed dose of 50 to 74 mGy. This risk is still small; one excess case of leukemia and one excess case of brain cancer is estimated per 10,000 head CT scans [10]. A large cohort study performed in Australia identified similar results with the additional finding of increased risk of solid cancers and an overall excess risk of about 0.125 cancers per sievert [11]. These studies have a potential selection bias by not excluding patients with congenital anomalies potentially at higher risk for leukemia and brain tumors [12]. Review of other smaller, likely underpowered, studies has not found a consistent association with postnatal medical radiation and childhood malignancies [6]. Our study found estimated effective doses from CVL fluoroscopic procedures to be well below these levels; however, no epidemiological studies have examined the long-term risks with quantified fluoroscopy exposure in children [13].

Our study identified significant variability among the surgeons in their caseload and fluoroscopic use. We found a correlation suggesting that FT decreased with a higher number of yearly CVL procedures. Because this study only reviewed one year of practice, we cannot correlate total number of cases with FT. We also did not evaluate the difficulty of the cases, which could be a possible confounding variable. However, this variability in FT and dose suggests operator dependence, which could possibly improve with further radiation training.

From the phantom simulations, we were able to derive that the default mode was being used the majority of the time for the fluoroscopic cases instead of the low dose mode. The low dose mode reduces the current by half; even lower doses are possible using pulsed mode options. Instituting standard use of low dose settings on the C-arm is a potential way to minimize patient exposure. We also identified inconsistent radiation safety practices among the surgeons. Few used appropriate protection and dose monitoring, despite yearly on-line radiation safety training. While we were not able to directly measure individual surgeon dosimeter wear patterns due to the retrospective nature of this study, the survey responses and the low values in the dosimeter reports indicate inappropriate use if any.

These findings suggest that on-line radiation training is an ineffective format at this institution and perhaps others. Of the two surgeons who did have formal training both reported inappropriate use of lead protection and one surgeon did not use the dosimeter. This is evidence for the need for periodic hands-on formal radiation training. In addition to basic principles of fluoroscopic systems and radiation exposure, formal hands-on radiation training should include fluoroscopic machine training with dose reduction techniques provided by a radiologist or qualified diagnostic medical physicist.

Using phantom modeling to estimate radiation exposure from scatter, we did find the radiation exposure to the surgeon was low. The majority of surgeons had yearly estimates of entrance exposure less than 2 mGy. This is well below the annual occupational radiation total body exposure recommendation from the ICRP of 20 mSv per year [1]. Given these

findings, it is still important to keep in mind the lack of epidemiological data regarding risks of occupational exposure to low dose ionizing radiation.

Estimation of occupational exposure on an epidemiologic scale is challenging given changes in dose reporting, dosimetry, and imaging technology. This emphasizes the need for dose monitoring and consistent safety practices [1]. Excess risks of leukemia, skin, and female breast cancer have been identified in medical radiation workers employed before 1950; there is minimal consistent data after this time. Occupational radiation-related dose-response epidemiological data are lacking for physicians and technologists performing fluoroscopically guided procedures [14]. Recent cohort studies have found increasing evidence of deterministic effects of radiation causing lens opacities at a lower dose than initially suspected [15]. A study of 69 nurses and 58 interventional cardiologists, with an estimated cumulative eye dose range of 0.1 to 18.9 Sv (from survey), demonstrated posterior subcapsular lens changes consistent with ionizing radiation exposure in 50% of physicians and 41% of nurses and technicians compared to 10% seen in age-matched controls [16]. The International Commission on Radiation Protection (ICRP) decreased the lens dose limit and now recommends an equivalent dose limit for the lens of the eye less than 20 mSv/year, averaged over a defined 5-year period, with no single year exceeding 50 mSv [15]. Given that the occupational hazards of medical imaging are not fully understood, all precautions should be taken to protect staff from radiation exposure, including lead shielding, barriers, and protective eyewear.

While the majority of pediatric and surgeon exposure during CVL placement is low, our findings emphasize that patients receive a significantly higher radiation dose than the physicians. This highlights the importance of reducing patient exposure. ALARA is an acronym for “as low as reasonably achievable” radiation exposure, and this concept is emphasized in children. It is a philosophy created from the recognition that children are more sensitive to radiation than adults. This stems from the theory of the no-threshold linear model that no level of radiation exposure is without consequence [17]. All efforts to reduce pediatric radiation exposure should be made. Effective fluoroscopic safety training can result in a significant decrease in patient dose; this is coupled with the added benefit of reduced operator exposure [18].

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Figure 1. Phantom patient and surgeon with skin dosimeter
Photograph of phantom modeling. Modeled surgeon left, anthropomorphic thorax phantom right with skin dosimeter leads attached.

Table 1
Fluoroscopic time and exposure by procedure

Patient exposure and fluoroscopic time by type of procedure performed in 2012. Frequency of procedure reported as percentage. Values of patient entrance exposure, fluoroscopic time (FT), and calculated patient effective dose per procedure type reported as median (IQR);

Procedure Type	Frequency (%)	Entrance Exposure (mGy)	FT (sec)	Effective Dose (mSv)
Port	53	0.86 (0.4, 2.2)	15.35 (6, 35)	0.14 (0.1, 0.3)
Tunneled line	28	0.49 (0.2, 1.9)	10.2 (5, 21)	0.12 (0.1, 0.3)
Tunneled dialysis	7	1.29 (0.5, 2.5)*	18.5 (8, 36)	0.16 (0.1, 0.3)
Dialysis catheter	5	1.00 (0.6, 1.6)	10.5 (6, 24)	0.12 (0.0, 0.2)
Central venous	6	0.29 (0.2, 0.8)	5.4 (3, 21)	0.08 (0.0, 0.3)
ECMO	1	---	47.4 (34, 141)	0.49 (0.4, 1.2)

* versus central venous (p<0.001); extracorporeal membrane oxygenation (ECMO) entrance exposure data not available.

Table 2**Fluoroscopic time and exposure by surgeon**

Patient and operator exposure by individual surgeon in 2012. Patient entrance exposure in milligray; calculated patient effective dose in millisieverts; fluoroscopic time (FT) per procedure in seconds; cumulative yearly FT exposure (surgeon) in minutes; calculated yearly scatter (surgeon entrance exposure) in milligray; and yearly (surgeon) dosimeter reports measured in millirem. DDE: deep dose equivalent; LDE: lens dose equivalent; SDE: shallow dose equivalent; M: minimum. FT, patient exposure, and calculated effective doses reported as median (IQR).

Cases per Surgeon	FT per Procedure	Patient Entrance Exposure	Patient Effective Dose	Surgeon Yearly FT	Surgeon Yearly Scatter	Surgeon Annual Dose Report (mrem)	
Surgeon	Cases	sec. (IQR)	mGy (IQR)	mSv (IQR)	min./year	mGy/year	DDE/LDE/SDE
A	24	14.1 (6, 26)	0.76 (0.3, 1.6)	0.15 (0.05, 0.24)	9.36	0.96	M/M/M
B	39	12.9 (6, 18)	0.77 (0.3, 1.2)	0.11 (0.08, 0.18)	13.23	1.27	3/3/3
C	16	33.5 (6, 122)	1.77 (0.7, 7.5)	0.29 (0.08, 1.10)	15.38	1.47	1/2/3
D	53	17.3 (5, 55)	0.70 (0.2, 3.4)	0.16 (0.04, 0.49)	33.46	2.99	2/2/2
E	5	22.9 (10, 33)	0.68 (0.3, 1.5)	0.20 (0.12, 0.27)	1.82	0.18	2/2/3
F	50	8.2 (5, 14)	0.49 (0.3, 1.0)	0.08 (0.05, 0.14)	12.26	1.28	4/4/4
G	19	36.4 (20, 72)	3.36 (1.1, 4.1)	0.37 (0.21, 0.57)	22.47	2.38	N.A.
H	71	6.9 (4, 15)	0.39 (0.2, 0.8)	0.07 (0.04, 0.20)	26.40	2.51	2/2/3
I	13	24 (11, 52)	1.70 (0.6, 2.8)	0.21 (0.12, 0.40)	10.82	1.15	M/M/M
J	51	12.4 (7, 47)	0.90 (0.3, 2.8)	0.18 (0.08, 0.36)	37.73	3.26	2/2/3
K	45	19.9 (7, 31)	1.30 (0.5, 2.3)	0.20 (0.06, 0.28)	20.61	1.85	2/2/2

Table 3**Surgeon response to survey of safety practices**

Self-evaluation survey of surgeon radiation safety practices. Full protection was considered thyroid shield, lead vest, and lead skirt. Values are percent of time.

Surgeon	No Lead Protection	Formal Training	Dosimeter Use	Full Protection	Vest Only	Apron Only	Vest And Apron	Thyroid And Apron	Barrier Use
A	0	No	80	5	5	5	85	5	5
B	--	--	--	--					
C	0	No	0	100					
D	--	--	--	--					
E	0	No	0	100					
F	0	No	10	0	100				
G	--	--	--	--					
H	20	No	30	0	80			5	
I	0	No	90	100					
J	60	Yes	0	0			40		
K	0	Yes	100	80	20				