

# Radiation Exposure During Operative Fixation of Pediatric Supracondylar Humerus Fractures: Is Lead Shielding Necessary?

Jeffrey E. Martus, MD, MS,\* Melissa A. Hilmes, MD,† Jared V. Grice, MS,‡  
Christopher M. Stutz, MD,§ Jonathan G. Schoenecker, MD, PhD,\* Steven A. Lovejoy, MD,\*  
and Gregory A. Mencio, MD\*

**Background:** Factors that impact radiation exposure during operative fixation of pediatric supracondylar humerus (SCH) fractures have been investigated; however, no studies have measured the equivalent dose at the patient's radiosensitive organs. Our hypothesis was that intraoperative fluoroscopy exposes pediatric patients to a significant radiation load and lead shielding of radiosensitive organs is important. The goal of the study was to quantify the patient's radiation exposure during the procedure by measuring the radiation load at the thyroid and gonads.

**Methods:** A prospective quality improvement project of radiation exposure during percutaneous fixation of isolated SCH fractures was performed over a 4-week period. The c-arm image intensifier was used as the operating table and radiation dosimeters were positioned over the thyroid and gonadal lead shields. Fluoroscopy times were recorded, doses were calculated, and the dosimeters were analyzed. To assure that the prospective cohort was representative of a larger population of SCH fractures, demographics and fluoroscopy time of the prospective cohort were compared with a 12-month retrospective cohort in which dosimetry was not performed.

**Results:** *Prospective cohort*—18 patients with type 2 (8) and type 3 (10) fractures were prospectively studied with intraoperative measurement of thyroid and gonadal radiation equivalent doses. Mean age was 4.9 years (1.9 to 9.5y) and mean weight was 21.4 kg (13.1 to 33.5 kg). Mean fluoroscopy time was 65.0 seconds (25.3 to 168.4s), and absorbed skin dose at the elbow was 0.47 mGy (0.18 to 1.21 mGy). The radiation dosimeters overlying the thyroid and gonads measured minimal radiation indicating equivalent doses of <0.01 mSv for all patients in the prospective cohort. *Retrospective cohort*—163 patients with type

2 (60) and type 3 (103) fractures were retrospectively studied. The mean age was 5.5 years (0.02 to 13.7y) and weight was 21.6 kg (2.0 to 71.9 kg). Mean fluoroscopy time was 74.1 seconds (10.2 to 288.9s), and absorbed skin dose at the elbow was 0.53 mGy (0.07 to 2.07 mGy). There were no statistically significant differences between the cohorts.

**Conclusions:** The smaller prospective cohort had fluoroscopy times and radiation doses that were not statistically different from the larger retrospective cohort, suggesting that the dosimeter measurements are representative of intraoperative radiation exposure during fixation of pediatric SCH fractures. The equivalent dose to the thyroid and gonads was minimal and approximates daily background radiation. Shielding of radiosensitive organs is appropriate when practical to minimize cumulative lifetime radiation exposure, particularly in smaller patients and when longer fluoroscopy times are anticipated.

**Level of Evidence:** Level 2.

**Key Words:** pediatric, supracondylar humerus fracture, fluoroscopy, radiation exposure

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## BACKGROUND

Displaced supracondylar humerus (SCH) fractures are inherently unstable and require operative treatment to prevent malunion. Fluoroscopy is an invaluable tool for reduction and percutaneous fixation of these common pediatric injuries; however, iatrogenic radiation exposure is a concern to patients and their families. Exposure to ionizing radiation may increase the lifetime risk for the development of cancer and these risks are greater for pediatric patients. The longitudinal studies arising from survivors of the atomic bomb in Japan suggest a significant increase in radiation-induced malignancies with whole body doses of radiation ranging from 5 to 150 mSv.<sup>1–5</sup> Studies of workers in the nuclear industry have also noted that radiation doses in this range were associated with the diagnosis of cancer.<sup>6,7</sup>

Despite frequent use of an intraoperative radiation source (surgeon directed fluoroscopy), many trauma and orthopaedic surgeons are unfamiliar with basic radiation

From the \*Division of Pediatric Orthopaedics; †Division of Pediatric Radiology, Monroe Carell Jr Children's Hospital at Vanderbilt; ‡Department of Radiology and Radiological Sciences, Vanderbilt University Medical Center, Nashville, TN; and §Department of Orthopaedics, Texas Scottish Rite Hospital for Children, Dallas, TX.

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Reprints: Jeffrey E. Martus, MD, MS, Division of Pediatric Orthopaedics, Monroe Carell Jr Children's Hospital at Vanderbilt, 2200 Children's Way, Suite 4202, Nashville, TN 37232-9565. E-mail: jeff.martus@Vanderbilt.edu.

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physics and adequate methods of radiation protection.<sup>8</sup> The following is a review of radiation concepts and terminology.<sup>9</sup> The biological effects of radiation depend upon the absorbed dose and the linear energy transfer (LET) specific to the type of radiation (x-rays, gamma-rays, or alpha particles). Air kerma is the preferred method for quantifying x-ray beam radiation, representing the kinetic energy released per unit mass. Units of air kerma are joules per kilogram (J/kg) or gray (Gy).

*Absorbed dose* is the radiation energy absorbed per unit mass and is dependent upon the tissue type (soft tissue, bone, etc.). Assuming no backscatter, entrance air kerma can be converted to an absorbed dose by multiplying with a tissue weighting factor that depends upon the tissue type and the photon energy (keV) of the x-rays.

*Equivalent doses* are used to describe biological damage that may result from different radiation types and are utilized for radiation protection purposes. These doses are expressed in sieverts (Sv) or roentgen equivalent in man (rem), where 100 rem is equivalent to 1 Sv (1 mrem = 0.01 mSv). Equivalent doses are calculated by multiplying the absorbed dose by the radiation weighting factor ( $W_R$ ) of the radiation source. X-rays are sparsely ionizing with a LET of approximately 1 keV/ $\mu$ m and a corresponding  $W_R$  of 1, as compared with high LET radiation sources such as alpha particles where  $W_R$  may be in the range of 20.

*Effective dose* is a calculated uniform whole body dose that has the same risk as a particular dose distribution. This is calculated by the summation of the equivalent doses for each irradiated organ multiplied by the organ weighting factor. This weighting factor is 0.01 for skin and bone surfaces, 0.04 for thyroid, 0.08 for gonads, and 0.12 for bone marrow, colon, lung, breast, and stomach. Effective doses represent the stochastic health risks of cancer induction and genetic effects. The risk of fatal cancer among adults secondary to radiation exposure has been estimated as 5% per Sv effective dose, while the risk may be 11% for a 5-year-old child.<sup>10-12</sup>

Fluoroscopy times and absorbed radiation doses at the elbow during operative fixation of pediatric SCH humerus fractures have been reported.<sup>13-16</sup> However, no studies have attempted to measure the amount of scattered radiation that reaches the patient's radiosensitive organs. The intensity of radiation decreases with the square of the distance from the radiation source, however, radiosensitive organs may be at risk during this fluoroscopic assisted procedure. The goal of this study was to quantify the radiation dose at the thyroid and gonads during fixation of pediatric SCH humerus fractures and to delineate the need for lead shielding. Our hypothesis was that intraoperative fluoroscopy exposes pediatric patients to a significant radiation load and lead shielding of radiosensitive organs is important.

## METHODS

An Institutional Review Board approved prospective quality improvement project was performed. Consecutive patients undergoing operative fixation of a

SCH fracture were studied over a 4-week period in 2012. Inclusion criteria were age below 14 years and an isolated, displaced SCH humerus fracture treated operatively with pin fixation. Patients with other fracture types or those patients requiring plate fixation were excluded.

Patients were managed with a standard intraoperative protocol. Supine positioning was utilized with a custom elbow table attachment that accommodates the c-arm fluoroscopy unit in an inverted position, with the elbow resting on a 6-cm thick padded support directly above the image intensifier. Lead shields were placed over the thyroid and gonads during the procedure due to the inverted position of the fluoroscopy unit (OEC 9800 Plus, General Electric, Atlanta, GA). Optically stimulated luminescent dosimeters (Landauer Luxel+, Glenwood, IL) were secured above the lead shields overlying the thyroid and gonads for the duration of the operative procedure (Fig. 1). The distance from the center of the image intensifier to the thyroid and gonadal regions was measured. After the procedure, the radiation dosimeters were submitted for analysis in a deidentified manner. Demographics including patient age, weight, fracture classification, and associated injuries were recorded. Fluoroscopy time was also collected.

To assure that the prospective cohort was representative of a larger population of SCH fractures, the demographics and fluoroscopy time of the prospective cohort were compared with a 12-month retrospective cohort in which dosimetry was not performed. This was an Institutional Review Board approved retrospective study of all pediatric patients below 14 years who had undergone pin fixation of an isolated, displaced SCH humerus fracture in 2011. Patients were identified through a search of billing records with appropriate Current Procedural Terminology codes. A chart review was performed and the data recorded were identical to the prospective cohort and included age, weight, fracture classification, and fluoroscopy time.

A radiation physicist (J.V.G.) measured the skin entrance exposure rates for the fluoroscopy unit utilizing a forearm phantom. The distance from the x-ray tube to the anterior elbow was estimated as 88 cm when using the fluoroscopy unit in an inverted position; the entrance skin dose rate at this position was calculated to be 0.43 mGy/min. An absorbed skin dose at the elbow was calculated for each patient in the prospective and retrospective cohorts utilizing this entrance skin dose rate and the recorded fluoroscopy times (absorbed dose = entrance dose rate  $\times$  fluoroscopy time). The demographics, fluoroscopy time, and absorbed skin doses at the elbow of the prospective and retrospective cohorts were compared statistically. *T* tests were used to compare continuous variables and Fisher exact tests were used for categorical variables. A *P*-value < 0.05 was used to indicate statistical significance.

## RESULTS

A total of 18 patients were prospectively studied with intraoperative measurement of thyroid and gonadal



**FIGURE 1.** Inverted c-arm positioning using the imaging intensifier as the operative table. Lead shielding with placement of optically stimulated luminescent dosimeters overlying the thyroid and gonads.

radiation equivalent doses. There were 8 type 2 and 10 type 3 fractures. Mean age was 4.9 years (1.9 to 9.5 y) and mean weight was 21.4 kg (13.1 to 33.5 kg). The mean distance from the image intensifier center to the thyroid was 28.9 cm (20 to 56 cm) and to the gonads was 43.0 cm (33 to 53 cm). The diameter of the image intensifier was 23 cm. Mean fluoroscopy time was 65.0 seconds (25.3 to 168.4 s), absorbed skin dose at the elbow was 0.47 mGy (0.18 to 1.21 mGy). The mean fluoroscopy times (86.6 vs. 38.0 s,  $P < 0.01$ ) and absorbed skin doses at the elbow (0.62 vs. 0.27 mGy,  $P < 0.01$ ) were greater for type 3 as compared with type 2 fractures. The radiation dosimeters

overlying the thyroid and gonads measured minimal radiation indicating equivalent doses of  $< 0.01$  mSv for all patients in the prospective cohort.

The retrospective study identified 163 patients with 60 type 2 and 103 type 3 fractures. The mean age was 5.5 years (0.02 to 13.7 y) and weight was 21.6 kg (2.0 to 71.9 kg). Mean fluoroscopy time was 74.1 seconds (10.2 to 288.9 s) and absorbed skin dose at the elbow was 0.53 mGy (0.07 to 2.07 mGy). The mean fluoroscopy times (92.2 vs. 43.2 s,  $P < 0.0001$ ) and absorbed skin doses at the elbow (0.66 vs. 0.31 mGy,  $P < 0.0001$ ) were greater for type 3 as compared with type 2 fractures.

The data from the prospective and retrospective cohorts are presented in Table 1. There were no significant differences between the cohorts.

### DISCUSSION

Factors that impact radiation exposure during the operative treatment of pediatric SCH humerus fractures have been studied. Bar-On et al<sup>13</sup> noted that the use of a surgeon operated foot switch and image collimation reduced the radiation dose. In addition, using a saw bone model, the authors noted that the inverted c-arm method minimized radiation exposure by positioning the elbow directly over the image intensifier. The effect of positioning has also been studied by Giordano et al<sup>17</sup> who determined in a cadaveric model that radiation exposure is minimized by decreasing the distance from the patient's surface to the image intensifier. The radiation dose may be reduced by a factor of 10 when the body part is adjacent to the image intensifier as compared with the radiation source. In contrast to these studies, Hsu and colleagues found that the use of inverted c-arm method resulted in 21% greater direct radiation exposure in a cadaveric model of pediatric SCH fracture fixation. This contradictory finding may be related to the higher c-arm settings (kVp and mA) required for adequate image quality in the inverted c-arm position as compared with the standard c-arm configuration for this cadaveric model.<sup>18</sup>

The mean fluoroscopy times required for percutaneous fixation of pediatric SCH fractures reported in the literature are similar to those recorded in this study. Bar-On et al<sup>13</sup> reported mean fluoroscopy times of 75 seconds (range, 1 to 565 s) for senior surgeons and 126 seconds (range, 27 to 431 s) for resident surgeons during

**TABLE 1.** Demographics and Radiation Exposure of the Prospective and Retrospective Cohorts

	Prospective Cohort (n = 18)	Retrospective Cohort (n = 163)	P
Age (y)	4.9 (1.9–9.5)	5.5 (0.02–13.7)	0.27
Weight (kg)	21.4 (13–34)	21.6 (2.0–72)	0.92
Type 2/type 3 fractures	8/10	60/103	0.55
Fluoroscopy time (s)	65.0 (25–168)	74.1 (10–289)	0.36
Absorbed skin dose at elbow (mGy)*	0.47 (0.18–1.21)	0.53 (0.07–2.07)	0.36
Distance from image intensifier center to thyroid (cm)	28.9 (20–56)	Not measured	NA
Distance from image intensifier center to gonads (cm)	43.0 (33–53)	Not measured	NA
Equivalent dose at thyroid/gonads (mSv)	$< 0.01$	Not measured	NA

\*Calculated: absorbed skin dose = entrance dose rate × fluoroscopy time.  
NA indicates not available.

operative fixation of 83 pediatric SCH fractures. In a study comparing fixation methods of pediatric SCH fractures, Kraus et al<sup>15</sup> noted a mean fluoroscopy time of 30.7 seconds (range, 9 to 121 s) for percutaneous fixation of 76 fractures. Another study investigating the direct radiation beam exposure to the surgeon during pin fixation of 78 pediatric SCH fractures found a mean fluoroscopy time of 34 seconds (range, 4 to 149 s).<sup>16</sup> In the current study, the mean fluoroscopy time was 74.1 seconds (range, 10 to 289 s) for the 163 fractures in the retrospective cohort.

The need and advisability for lead shielding of areas outside of the beam during pediatric fluoroscopy is unclear.<sup>19</sup> In Tennessee, the Division of Radiologic Health specifies that “Gonadal protection, by use of gonadal shields, shall be provided and used for patients who have not passed the reproductive age, during each radiographic procedure in which the gonads are in the useful beam or proximate thereto, except in those cases in which the shield would interfere with the diagnostic procedure. The protection provided shall be equivalent to 0.25 millimeters of lead.”<sup>20</sup> The International Commission on Radiologic Protection recommends “shielding of the child’s body in the immediate proximity of the diagnostic field. The use of additional shielding should also be considered for certain examinations to protect against external scattered and extrafocal radiation. When the breasts, gonads, and/or thyroid lie within 5 cm of the primary beam, they should be protected whenever this is possible without impairing the necessary diagnostic information.”<sup>21</sup> Within the prospective cohort, the mean distance to the center of the image intensifier was 28.9 cm for the thyroid and 43.0 cm for the gonads. As the diameter of the image intensifier was 23 cm, the radius of 11.5 cm decreases the mean distance to the edge of the primary beam to 17.4 cm for the thyroid and 31.5 cm for the gonads. The shorter arm length of younger, smaller children will necessitate that radiosensitive organs are closer to the diagnostic field as compared with older, larger children and may justify shielding.

The annual natural background radiation has been estimated worldwide as 2.4 mSv with a typical range of individual doses of 1 to 13 mSv.<sup>22</sup> Within the retrospective cohort, the mean equivalent skin dose at the elbow was 0.53 mSv. In the prospective cohort, the mean equivalent skin dose at the elbow was 0.47 mSv while the equivalent doses at the level of the thyroid and gonads was minimal (< 0.01 mSv). These doses at the radiosensitive organs approximate daily natural background radiation (0.007 mSv/d). The prospective cohort of 18 fractures had similar fluoroscopy times and radiation doses as the larger retrospective cohort of 163 fractures, suggesting that these dosimeter measurements are representative.

Clinically important deterministic effects, such as radiation-induced skin damage, cataracts, or sterility, occur with exposure at a threshold dose of 2 Gy.<sup>9</sup> In this study, the calculated absorbed skin doses at the elbow and the measured doses at the radiosensitive organs were minimal in comparison with this threshold. However,

radiation exposure less than this threshold may produce stochastic effects such as carcinogenesis or the induction of hereditary effects.<sup>9</sup> The severity of these effects is independent of the dose. Stochastic effects have been conservatively estimated to follow the linear no-threshold model where greater doses increase the probability of the effect and the risk is cumulative with repeated exposures.<sup>10</sup> Children are at higher risk due to increased tissue radiosensitivity and greater life expectancy to manifest radiation-induced effects. Given these factors, we are unable to recommend against lead shielding of radiosensitive regions when practical.

In summary, the radiation dose to the patient’s radiosensitive organs during fixation of SCH fractures was minimal within a prospective cohort of 18 patients. However, the goal is to minimize the patient’s exposure to ionizing radiation to levels that are “as low as reasonably achievable” with the concern that a radiation dose of any magnitude may produce some level of detrimental effect.<sup>23,24</sup> Shielding of radiosensitive organs is appropriate when practical to minimize cumulative lifetime radiation exposure, particularly in smaller patients and when longer fluoroscopy times are anticipated.

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