Analysis of Intraoperative Radiation Exposure in Paediatric Orthopaedic and Trauma Surgery: A comparative cohort study

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INTRODUCTION:

The literature on radiation exposure in paediatric orthoapedic trauma surgery is limited despite increase of use in medical treatment and growing evidence on adverse effects. Interestingly, much more information is available on preoperative and postoperative imaging which potentially helps to limit radiation exposure. However, also the intraoperative applied radiation is of importance but underrepresented in the current knowledge which might lead to inappropriate use intraoperatively. Because of possible, detrimental longterm effects on child health, this study sought to reliably analyze the intraoperative radiation exposure.

METHODS:

The study was conduced at a tertiary referral center analyzing 2,271 cases of 1,965 patients (median age 9 [IQR, 6-12] years, 41% female) who underwent pediatric orthopedic trauma surgery between 2016 and 2021. All standard patient information were collected and the dose reports were retrospectively analyzed. The anatomical regions were categorized as shoulder, humeral shaft, elbow, forearm, wrist / hand, hip, femur, knee, tibia, foot / ankle, multilevel surgery upper extremity and multilevel surgery lower extremity.

Radiation exposure was measured as dose area product ($cGycm^2$) from intraoperative reports. Subsequently, factors in relation to one preoperative image of the region (relative dose area product) and in relation to a weight-corrected chest x-ray (relative dose area product chest) were calculated. Further, effective dose (µSV) was estimated by applying standardized conversion factors.

Statistical analysis was performed using RStudio (Boston, USA). All were values were given as median and interquartile range (IQR) because of unequal distribution.

RESULTS:

A total of 195,667 x-rays were included into the analysis comprising 1,584 (70%) trauma cases and 687 (30%) elective orthopaedic cases comprising 1,584 (70%) trauma cases and 687 (30%) elective cases (**Table 1**). The majority of cases (56%; n=1,245) was performed around the upper extremity, followed by lower extremity (41%; n=895).

The mean dose area product measured 30 (IQR, 14 to 59) $cGycm^2$ with a median of 62 (IQR, 34 to 107) exposure events per case. Overall, trauma surgery reached a median of 29 (IQR, 14 to 56) $cGycm^2$ whereas elective surgery reached 30 (IQR, 11 to 71) $cGycm^2$ (difference between groups $p = 0.4$). Similarly, upper extremity cases lead to 27 (IQR, 14 to 49) $cGycm^2$ and lower extremity cases led to 33 (IQR, 12 to 76) $cGycm^2$ ($P < 0.001$). The highest dose area products were seen for cases around the shoulder, humerus and femur with values of 87 (IQR, 36 to 196) $cGycm^2$, 58 (IQR, 29 to 119) $cGycm^2$ and 54 (IQR, 19 to 114) $cGycm^2$, respectively.

The relative dose area product reached a factor of 26 (IQR, 8 to 69), with the largest factors for multilevel surgery at the upper extremity, elbow and forearm with factors of 89, 56 and 55, respectively. The lowest factors were seen around the hip, knee and spine reaching 7,8 and 8, respectively. (**Figure 1**).

The relative dose area product chest reached highest values in surgeries around the hip, multilevel upper extremity and shoulder with values of 27, 26 and 22, respectively.

Analysis of effective dose revealed a median exposure of 13 (IQR, 3 to 31) µSv with highest values for spine, hip and shoulder reaching 98.08 (IQR, 49.03 to 158.5) µSv, 72.54 (IQR, 29.51 to 186.19) µSv and 55.9 (22.86, 125.54) µSv, respectively (**Figure 2**).

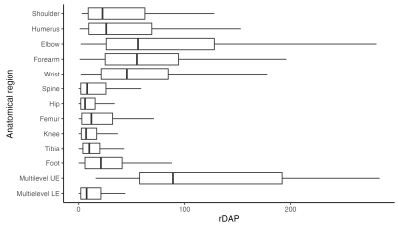
DISCUSSION AND CONCLUSION:

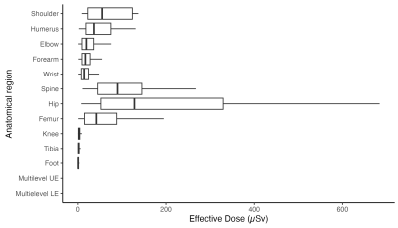
The study aimed to raise awareness of intraoperative radiation exposure during paediatric orthoapedic trauma surgery and to highlight the associated risks, particularly in paediatric patients. The overall dose area product exceeded that of a single preoperative x-ray by a median factor of 26 and a standard chest x-ray by a median factor of 11. While the calculated effective dose was acceptable (median 13 µSv), several procedures reached values close to 1000 µSv.

The radiation exposure is a particular concern because stochastic radiation effects can increase cancer risk, especially in children due to faster cell division and longer life expectancy. In light of this, exposure should adhere to the as low as reasonable achievable ("ALARA") principle. Although national reference levels for diagnostic exist, intraoperative data remain scarce. The study addressed this gap also excluding low-exposure procedures like mobilization under anesthesia.

In detail analysis revealed the highest values close the trunk including shoulder and hip surgery. Further, trauma cases generated more radiation, possibly because of complicated reduction maneuvers. Outliers showed relative dose area products up to 200 compared to one preoperative x-ray of that region. Compared to previous studies, the present work uniquely calculated effective doses across anatomical regions which is essential to compare the effect between different anatomical regions.

The main limitations include the retrospective design and use of adult dose conversion factors. Still, findings support the need for further reduction of intraoperative radiation, and exploration of non-radiative alternatives for intraoperative imaging and guidance.





Characteristic	Overall N = 2,271[1]	Elective N = 687[1]	Trauma N = 1,584[1]	p-value[2]
Age (y)	9.0 (6.0, 12.0)	12.0 (8.0, 14.0)	8.0 (6.0, 11.0)	<0.001
Female	921 (41%)	323 (47%)	598 (38%)	<0.001
Weight (kg)	32 (22, 48)	40 (24, 55)	29 (21, 43)	<0.001
Duration surgery (min)	71 (43, 118)	129 (78, 213)	58 (37, 87)	<0.001
Duration radiation (s)	62 (32, 109)	34 (18, 66)	74 (43, 123)	<0.001
Number of pictures	62 (34, 107)	42 (22, 81)	71 (43, 116)	<0.001
DAP (cGycm^2)	30 (14, 59)	30 (11, 71)	29 (14, 56)	0.4
rDap	26 (8, 69)	8 (2, 19)	42 (17, 92)	<0.001
rDap chest	11 (4, 23)	10 (4, 24)	11 (5, 22)	0.2
Effective dose (μSv)	13 (3, 31)	4 (1, 45)	15 (5, 29)	<0.001
Upper / lower extremity				<0.001
Lower Extremity	895 (41%)	554 (88%)	341 (22%)	
Spine	68 (3.1%)	66 (10%)	2 (0.1%)	
Upper Extremity	1,245 (56%)	12 (1.9%)	1,233 (78%)	
Anatomical region				
Shoulder	12 (0.5%)	1 (0.1%)	11 (0.7%)	
Humerus	47 (2.1%)	5 (0.7%)	42 (2.7%)	
Elbow	462 (20%)	4 (0.6%)	458 (29%)	
Forearm	372 (16%)	1 (0.1%)	371 (23%)	
Wrist	352 (15%)	1 (0.1%)	351 (22%)	
Spine	68 (3.0%)	66 (9.6%)	2 (0.1%)	
Hip	160 (7.0%)	152 (22%)	8 (0.5%)	
Femur	199 (8.8%)	82 (12%)	117 (7.4%)	
Knee	189 (8.3%)	173 (25%)	16 (1.0%)	
Tibia	156 (6.9%)	56 (8.2%)	100 (6.3%)	
Foot	191 (8.4%)	91 (13%)	100 (6.3%)	
Multilevel UE	7 (0.3%)	0 (0%)	7 (0.4%)	
Multilevel LE	56 (2.5%)	55 (8.0%)	1 (<0.1%)	

[1]Median (IQR); n (%)
[2]Wilcoxon rank sum test; Pearson's Chi-squared test