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Assessment of patient and neurosurgeon radiation exposure using a direct-reading dosimeter during transpedicular fixation for thoracic and lumbar spine injuries

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ABSTRACT

Introduction. Individual dosimetry is routinely performed using thermoluminescent dosimeters (TLDs). Total dose is accumulated in these devices and periodically recorded by an accredited laboratory. This method does not provide real-time information on intraoperative radiation exposure.

Objective. To compare X-ray doses received by patients with traumatic thoracic and/or lumbar spine injury during open and minimally invasive interventions.

Material and methods. Ninety-two patients underwent surgery for thoracic and/or lumbar spine injury. Intraoperative analysis included dose-area products (DAP, cGy·cm^2), individual TLD dosimeter readings of surgeons. Individual radiation dose equivalent was determined using four direct-reading dosimeters positioned on the operating table at distances of 0, 40, 80, and 120 cm from direct beam of radiation source.

Results. Fifty-four patients underwent open surgery, 38 – transcutaneous procedure. Mean DAP was 2171 cGy·cm^2, mean radiation dose equivalent — 1.6 mSv. Minimally invasive procedures were associated with significantly higher radiation exposure: median DAP 3408.8 cGy·cm^2 and dose equivalent 2.3 mSv compared to 327.8 cGy·cm^2 and 0.2 mSv for open surgeries. Neurosurgeon radiation exposure did not exceed standards.

Conclusion. Patient radiation exposure is significantly higher during minimally invasive procedures compared to open surgeries (mean dose equivalent 3 mSv versus 0.6 mSv). Understanding the patterns of radiation field is necessary for informed and safe use of X-rays.

Keywords: *thoracic and lumbar spine fractures, transpedicular fixation, radiation dose, radiation dose equivalent.*

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Introduction

Modern implants and minimally invasive techniques improved treatment outcomes in patients with spinal injuries. A negative consequence of minimally invasive spine fusion is intraoperative X-ray exposure for the patient and staff [1–5]. In routine practice, individual dosimetry is performed using thermoluminescent dosimeters (TLDs). The last ones accumulate total dose with periodic control by an accredited laboratory. Unfortunately, this method does not provide real-time information on intraoperative radiation exposure. This is important because X-ray dose

Table 1. **Inclusion and exclusion criteria.**

Inclusion criteria	Exclusion criteria
— patients older 18 years; — unstable fractures of thoracic and/or lumbar spine; — spine fusion with or without decompression; — C-arm of same type for all patients; — informed consent to participate in study	— pathologic fractures (osteoporotic, neoplastic etc.); — vertebral bone density at the supposed level of fusion, measured with preoperative CT, less than 100 HU; — decompensated somatic status; — any malignant tumor; — pregnancy; — acute infectious disease; — congenital diseases of the spine or extremities

received by the patient depends on actions of surgeon. Although amount, quality and adequacy of protection along with distance to X-ray source are known factors determining radiation exposure, radiation dose is difficult to be determined in real time [1].

The purpose of the study was to compare X-ray doses received by patients with traumatic thoracic and/or lumbar spine injuries during open and minimally invasive procedures.

Material and methods

The study was conducted at the Neurosurgical Department of the Sklifosovsky Research Institute for Emergency Care between January 1, 2021 and December 1, 2024. In accordance with objective, we selected patients considering inclusion and exclusion criteria **(Table 1)**.

All patients underwent open or minimally invasive (transcutaneous) fusion procedure. This study did not influence surgical treatment that was fully consistent with modern clinical guidelines.

All intraoperative manipulations were performed on a Siemens Arcadis Orbic 3D (Germany) C-arm with a tube-to-receiver distance of 164.1 cm and working field of view diameter of 17 cm. According to the manual for this system, pulse voltage on the tube varied from 50 to 125 kV. All examinations were performed in fluoroscopy mode with automatic exposure control. Voltage and current on the X-ray tube varied in real time depending on thickness and density of anatomical area being examined. Appropriate dose-area products (DAP, sGy • cm^2), measured by standard C-arm dosimeter, were recorded.

We intraoperatively analyzed individual equivalent of radiation dose Hp (10) (dose equivalent) using four direct-reading Arrow-Tech W138-S photon (gamma and X-ray) radiation dosimeters (mSv). These dosimeters have a tissue-equivalent housing and allow for accurate measurements in a pulsed X-ray field. Individual dose equivalent measurement range of dosimeters is 0—2 mSv with a scale division value of 0.1 mSv. The limits of permissible basic relative error of individual dose equivalent measurements are ±15%. One dosimeter (#1) was located on the operating table in direct beam of radiation source. It was visible in frontal and lateral images. Other dosimeters were placed at distances of 40, 80, and 120 cm from direct beam of radiation source (dosimeters #2—4, respectively). We visually recorded data from direct-reading dosimeter, as specified in instructions. For each surgical procedure, we also considered surgery time, surgeon's name, surgical procedure (open or transcutaneous), fracture type, number of fractured vertebrae, number of screws and DAP measured by standard C-arm dosimeter. In addition, each surgeon used a personal DTU-1 TLD dosimeter (42×28×18 mm) placed on the chest (for men) or the waist (for women) under protective one-sided apron (lead equivalent protection Pb 0.35/100). Readings from this dosimeter were recorded in an accredited laboratory.

Table 2. **Demographic data.**

Variable	Value
Male/female, *n*	47/45
Age, years, Me; min—max	53; 19—81
Thoracic/lumbar level of injury, *n*	16/76
Number of unstable vertebrae, *n*, 1/2/3	84/3/1
AOSpine type of fracture, *n*, A/B/C	83/6/3
Surgery time, min, Me; min—max	167; 35—490
Mean DAP, sGy • cm^2, mean ± SD	2171±2168
Mean dose equivalent on dosimeter # 1, mSv, mean ± SD	1.6±1.6

We recorded all data in a spreadsheet and analyzed them using Statistica 12.0 software (StatSoft Inc., USA). Distribution normality was analyzed using the Shapiro-Wilk test. We compared continuous data with non-parametric distributions using the non-parametric Mann-Whitney U-test or the Kruskal-Wallis test. Between-group comparisons of categorical and dichotomous variables were performed using the Pearson χ^2 test or the two-tailed Fisher's exact test (F-test). The null hypothesis was rejected at $p<0.05$.

The study was conducted in accordance with the Declaration of Helsinki. All patients were informed about measurements and had access to results of these measurements.

Results

There were 361 interventions for thoracic and lumbar spine injuries at the Sklifosovsky Research Institute

Table 3. **Statistical analysis of X-ray ionization parameters.**

The parameter under study	*n*	Mean DAP, sGy·cm²	*p*-value, test	Average value of dose equivalent of dosimeter No. 1, mSv	*p*-value, test
Level of injury					
Thoracic	16	2340.8±2257.3	0.4, χ^2	1.7±1.5	0.4, χ^2
Lumbar	76	2135.5±2135.5		1.6±1.6	
Number of damaged vertebrae					
1	84	3407.4±3123.7	0.5, K–W	2.4±2.0	0.51, K–W
2	3	3456.3±2424.7		2.8±2.0	
3	1	7791.4		5.7	
Number of screws					
4	50	1972.9±1972.9 (493.2 per a screw)	0.0006, K–W (per a screw — 0.08)	1.6±1.6	0.02, K–W (per a screw — 0.08)
6	3	942.3±942.3 (157.4 per a screw)		0.7±0.7	
8	39	5408.8±3617.2 (676.1 per a screw)		3.5±2.3	
Technique					
Open	54	632.5±632.5	0.00001, χ^2	0.6±0.6	0.0001, χ^2
Minimally invasive (MIS)	38	4351.7±3059.4		3±1.9	
Surgeon					
1	21	2770.1±2770.1	0.19, K–W	2.1±1.9	0.19, K–W
2	14	1511.6±3092.2		1.3±1.2	
3	30	2227.0±2227.0		1.4±1.4	
4	11	1794.4±1676.9		1.4±1.2	
5	16	2116.8±2116.8		1.7±1.7	
Fracture type					
A	83	3600±3349.5	0.5, K–W	2.5±2.1	0.5, K–W
B	6	2943.6±899.4		2.3±0.5	
C	3	3461.2±2992.0		2.4±2.3	
Extent of surgery					
Fusion only	62	3327.4±2610.2	0.07, χ^2	2.5±1.8	0.87, χ^2
Decompression + fusion	30	2422.7±2422.7		1.7±1.7	

Note: K–W — Kruskal–Wallis test.

for Emergency Care between January 1, 2021 and December 1, 2024. Ninety-two patients (25%) were eligible. Demographic data of patients are presented in **Table 2**.

The number of men and women was similar (47 men and 45 women). The median age was 53 years (19—81 years). Patients with compression or compression-comminuted injury of one lumbar vertebra prevailed (type A — 83 patients). Fifty patients had one damaged vertebra, 41 patients — 2 vertebrae, 1 patient — 3 vertebrae. Mean surgery time was 167 min (range 35—490), mean DAP – 2171±2168 sGy·cm² (min 3, max 125460), mean dose equivalent — 1.6±1.6 mSv (min 0, max 8). Statistical evaluation of all parameters was performed **(Table 3)**.

Level of injury, number of damaged vertebrae, surgeon and fracture type do not significantly affect radiation exposure.

When analyzing radiation dose depending on the number of screws, we obtained expectable significant relationship (p=0.0006, Kruskal–Wallis test). However, analysis of DAP for each screw (493.2 sGy·cm² per a screw for four-screw fixation, 157.4 for six-screw fixation and 676.1 for eight-screw fixation) found no significant relationship. Lower radiation exposure following six-screw fusion was explained by small number of patients scheduled for this intervention (3 patients). Of these, 2 ones underwent classic open approach.

Dose equivalents presented by dosimeter #1 varied depending on insertion method and number of screws **(Table 4)**.

Minimally invasive screw placement significantly increased radiation exposure to the patient and staff (DAP 327.8 sGy·cm² (min 3, max 8110) for open procedures vs. 3408.8 sGy·cm² (min 480.3, max 12546) for minimally invasive interventions). Dose equivalent was 0.2 (0—5.8) and 2.3 (0.5—8) mSv, respectively **(Fig. 1)**.

Radiation exposure for each surgeon did not differ significantly depending on surgical method. Thus, radiation exposure was the same in subgroups of classical and minimally invasive techniques for all surgeons **(Table 5)**.

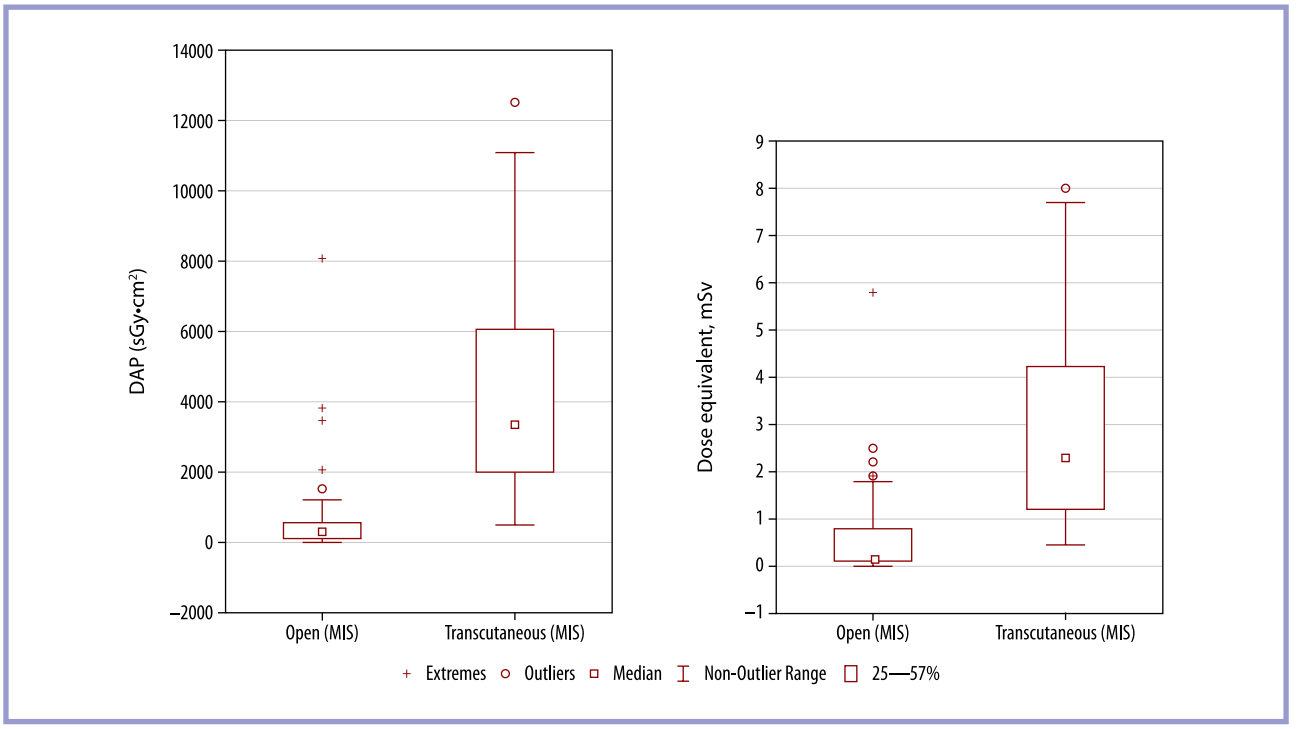

Fig. 1. **DAP (sGy·cm²) and dose equivalent (mSv) for open and transcutaneous fusion procedures.**

According to data from direct-reading dosimeters, the highest dose equivalent was recorded in zone of X-ray beam passage and decreased with distance from this beam **(Table 6**, **Fig. 2)**.

For 54 open procedures, mean dose equivalent for the first dosimeter (located in radiation beam) during a single procedure (mean time 191.3 minutes) was 0.6 mSv (median 0.2, range 0—5.8); for the second dosimeter (40 cm from the beam) — 0.07 (median 0.005, range 0—0.7 mSv); for the third dosimeter (80 cm from the beam) – 0.01 (median 0, range 0—0.2). The fourth dosimeter did not register radiation at a distance of 120 cm.

For 38 minimally invasive interventions (mean duration 199.5 min), mean dose equivalent for the first dosimeter was 3 mSv (median 2.3, range 0.5—8); for the second dosimeter — 0.41 (median 0.36, range 0.01—1); for the third

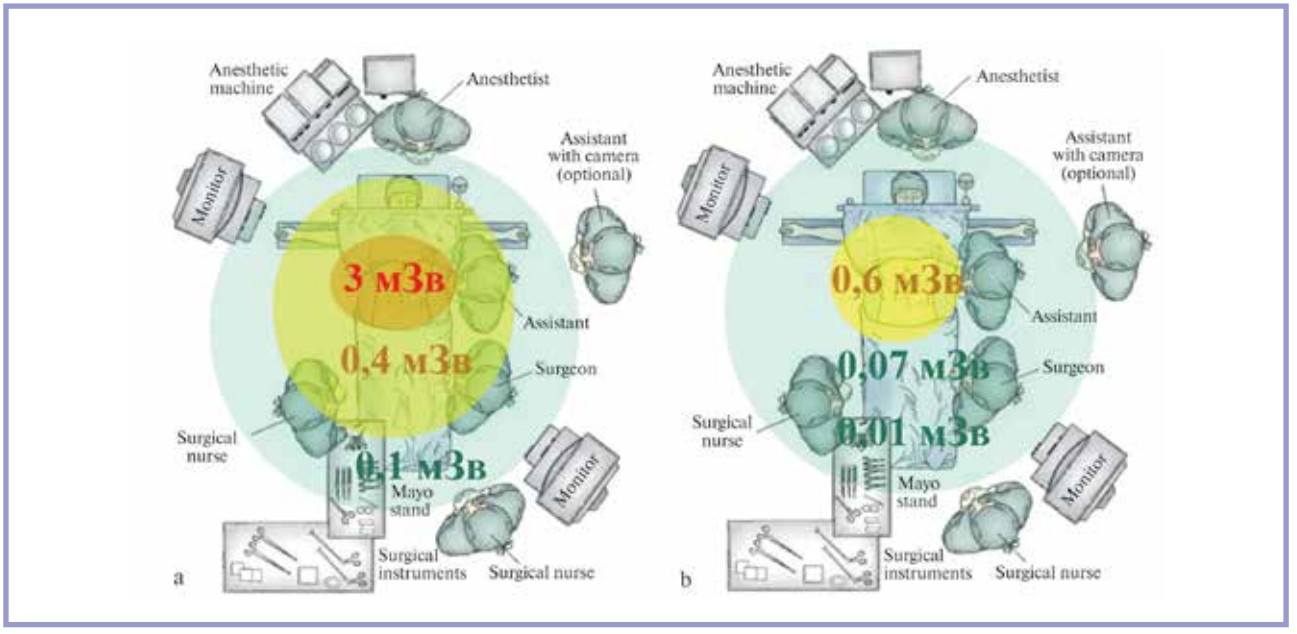

Fig. 2. **Ionizing radiation zones during minimally invasive (a) and open (b) procedures.**

Table 4. **Dose equivalents for different techniques.**

	4 screws	6 screws	8 screws
Dose equivalent for minimally invasive procedure, mSv, Me [upper – lower quartiles]	2.2 [1.6–3.1]	1.8	4.1 [2.2–5.8]
Dose equivalent for minimally invasive procedure per one level, mSv, Me [upper – lower quartiles]	1.1 [0.8–1.6]	0.6	1 [0.6–1.5]
Dose equivalent for open surgery, mSv, Me [upper – lower quartiles]	0.3 [0.1–0.9]	0.2	1.8 [0.85–2.2]
Dose equivalent for open surgery per one level, mSv, Me [upper – lower quartiles]	0.15 [0.1–0.5]	0.07	0.45 [0.2–0.6]

Table 5. **Radiation exposure depending on surgeon and surgical technique.**

Surgeon	Number of interventions, *n*	Open procedures, *n*	Mean DAP in open procedures, sGy·cm^2	Mean time of open surgery, min	Minimally invasive procedures, *n*	Mean DAP in minimally invasive procedures, sGy·cm^2	Mean time of minimally invasive surgery, min
1	21	13	670.5	155	8	5252	165
2	14	10	228.2	209	4	4719.7	156.3
3	30	17	476	188.8	13	4518.9	225.2
4	11	5	279.1	297.5	6	2931	269.6
5	16	10	676.9	166	6	4521.7	148.3
Total	92	54	632.5	191.3	38	4351.7	199.5

Table 6. **Records of direct-reading dosimeters Arrow-Tech.**

Dosimeter	Distance from radiation beam, cm	Mean dose equivalent for minimally invasive surgery (38 surgeries), mSv	Mean dose equivalent for open surgery (54 surgeries), mSv
1	0	3	0.6
2	40	0.4	0.07
3	80	0.1	<0.1
4	120	<0.1	<0.1

dosimeter — 0.1 (median 0.1, range 0—0.3); for the fourth dosimeter — 0.01 (median 0, range 0—0.1) mSv.

Distribution of isodoses in horizontal plane for minimally invasive and open interventions at thoracic and lumbar spine is presented in **Fig. 2**.

In all surgeons, we recorded TLD data over a 4-year experiment. None had radiation doses exceeded the standards established for personnel working in contact with ionizing radiation (maximum 1.5, minimum 1.0 mSv).

Discussion

Surgeons receive the highest intraoperative radiation dose during fluoroscopy due to their proximity to radiation scatter zone.

Ionizing radiation in medicine is unsafe. According to some estimates, medical imaging increases cumulative risk of malignant tumors by 7.1% [2]. Additional relative individual risk of tumors is 5% per 1 Sv [6].

Radiation exposure to surgeons during spinal fusion is 4—12 times higher compared to surgeries on other parts of musculoskeletal system. This is especially true considering widespread imaging in minimally invasive and percutaneous procedures [1, 3, 7].

In this study, we measured dose equivalent of X-ray (photon) radiation using an Arrow-Tech dosimeter with tissue-equivalent housing. Thus, it can be assumed that its value corresponds to effective dose.

In our study, mean effective radiation dose to the patient following open surgery was 0.2—0.6 mSv, for minimally invasive surgery — 2.3—3 mSv. According to available literature data, mean effective dose in open surgery for thoracic and lumbar spine injuries in adults was 0.393 mSv per a level, for minimally invasive surgery – from 0.611 to 1 mSv per a level [8—10]. In our study, dose equivalent per a level was 0.07—0.45 mSv for open surgery and 0.6—1.1 mSv for minimally invasive surgery **(Table 4)**. This is fully consistent with literature data.

Barrier protection (apron, cervical collar, goggles) is mandatory. Effective dose recorded by personal dosimeters of surgeons (placed under protective apron at the chest level) did not exceed 2 mSv per a year. This does not take into account radiation load on surgeon's hands direct-

ly exposed to radiation and receiving effective dose comparable to patient irradiation. According to the «Radiation safety standards NRB-99/2009», equivalent dose of planned increased radiation exposure to the hands can reach 2.000 mSv. This would correspond to 5.336 transcutaneous interventions over a career.

Although annual occupational exposure of surgeons is below the established permissible doses (no more than 1.5 mSv), any reduction in personnel radiation exposure remains desirable. Indeed, long-term consequences of chronic low-grade radiation exposure are currently unclear [3, 11, 12].

Study simitations

A methodological limitation is that direct-reading dosimeter could not be positioned in radiation field center, as this would hinder surgical work. Therefore, dosimeter #1 was positioned to the side of the patient. Nevertheless, this dosimeter was in direct radiation beam and visible in frontal and lateral images.

Conclusion

1. Intraoperative radiation exposure in surgery for traumatic thoracic and lumbar spine injuries is not significantly associated with level of injury, number of damaged vertebrae or type of spinal fracture.
2. Minimally invasive procedures contributed to significantly higher radiation exposure to patients compared to open procedures. Mean dose equivalents in the region of interest were 3 (0.5–8) and 0.6 mSv (0—5.8 mSv), respectively.
3. Transcutaneous fluoroscopy-guided screw placement did not exceed permissible dose limits for group B personnel. None surgeon had annual effective dose over 1.3 mSv.
4. Personnel awareness and clarity of radiation field patterns (dose) are important factors for informed use of radiation in medical practice.

Author contribution:
Concept and design of the study — Grin A.A., Kordonsky A.Yu., Karanadze V.A., Popov P.B., Beskin L.I.
Collection and analysis of data — Kordonsky A.Yu., Popov P.B., Ivanov E.M., Abdrafiev R.I., Borodin A.N., Saidov R.S.
Statistical analysis — Kordonsky A.Yu., Tupikin A.V.
Writing the text — Kordonsky A.Yu.
Editing — Grin A.A., Popov P.B., Beskin L.I., Tupikin A.V.

The authors declare no conflicts of interests.

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COMMENT

This article is devoted to radiation exposure to patients and staff during open and minimally invasive spinal neurosurgery. Both study groups were equivalent regarding key statistical parameters. An important positive aspect is modern method of dosimetry based on direct-reading dosimeters. Accuracy of their measurements of individual equivalent dose is higher compared to standard dosimetry based on thermoluminescent devices.

The authors demonstrated that patients were exposed to significantly higher irradiation in minimally invasive procedures. Legislative regulation currently does not apply to situations involving medical radiation. However, the benefit to a person from exposure should not exceed the risk of potential harm caused by radiation in accordance with principles of radiation safety (justification and optimization). Radiation should be maintained as low as achievable, and any radiation dose reduction is desirable. Nevertheless, radiation doses to patients and staff were trivial in traditional and minimally invasive procedures. This allows us to choose surgical technique according to clinical situation and not consider slightly lower radiation exposure associated with traditional procedures an advantage.

As a minor comment, it would be more correct to use the official term «personal protective equipment» as used in SanPiN 2.6.1.1192-03 instead of the term «barrier protection equipment».

This article is useful for various specialists involved in fluoroscopy-guided procedures.

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