



RADIATION EXPOSURE DOSES OF SURGEONS PERFORMING SPINE SURGERIES

M.V. Kubasov¹, M.N. Kravtsov^{1,2,3}, S.S. Sarycheva⁴, E.N. Shleenkova⁴, D.V. Svistov¹

¹S.M. Kirov Military Medical Academy, St. Petersburg, Russia;

²Research Institute of Emergency Medicine n.a. I.I. Dzhanlidze, St. Petersburg, Russia;

³North-West State Medical University n.a. I.I. Mechnikov, St. Petersburg, Russia;

⁴St. Petersburg Research Institute of Radiation Hygiene n.a. Prof. P.V. Ramzaev, St. Petersburg, Russia

Objective. To determine the radiation doses of surgeons performing spinal stabilization operations using fluoroscopy and X-ray.

Material and Methods. Design: prospective study and description of a case series. The sample included the most dose-related spine stabilization techniques: percutaneous transpedicular fixation (PTF, $n = 11$) and puncture kyphoplasty (PKP, $n = 10$). Effective radiation doses and equivalent radiation doses to the lenses of the eyes and the skin of the hands were evaluated.

Results. In the PTF and PKP groups, the following values were obtained, respectively: effective radiation doses to the surgeon — 0.07 mSv and 0.09 mSv; equivalent radiation doses to the lens of the eye — 1.2 mSv and 2.45 mSv, and to the skin of the hands — 11.96 mSv and 5.59 mSv.

Conclusion. The obtained values of effective radiation doses to the surgeon correspond to the recommended standards for radiation exposure to operating room personnel. The safe level of radiation will be exceeded after approximately 150 transpedicular fixation procedures or 82 PKPs, without taking into account other surgical interventions performed under radiographic guidance.

Key Words: transpedicular fixation; kyphoplasty; radiography; fluoroscopy; radiation safety; effective radiation doses; equivalent radiation doses.

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Because of an increasing number of minimally invasive spine surgeries, spine surgeons (neurosurgeons and traumatologists) are exposed to roentgen radiation, which is associated with a probable elevation in the risk of stochastic effects [1]. The reduction of exposure time, the use of personal radiation protection equipment, and the use of CT navigation during interventional procedures on the spine obviously decrease the exposure of all members of the surgical team to ionizing radiation [2, 3]. Nevertheless, the challenge of dosimetric monitoring for this category of medical professionals in the Russian Federation cannot be currently assumed to be resolved.

Russian medical specialists whose activities involve exposure to ionizing radiation are classified into categories. Doses for specialists of Group A (who work directly with man-made sources of ionizing radiation) are monitored through the technique of individual dosimetric monitoring (IDM). This technique involves determining a specialist's individual exposure doses based on the measurements findings of the exposure of the body or specific organs of each

medical specialist. This is done using personal dosimeters worn on the surface of the body during the monitoring period (which is quarterly). For specialists of Group B (who are not directly exposed to ionizing radiation sources but are within the area of influence), doses are calculated through area dosimetric monitoring. Specialists of the surgical team involved in special radiological examinations, whose working conditions are associated with a sharply heterogeneous radiation field, are classified as Group A specialists by internal order of the medical institution, in accordance with the conduct of IDM [4–6]. This category also covers spine surgeons, who are exposed to high dose difference across the body [7–9]. Chauhan et al. [7] and Yoshihara et al. [8] showed that the lenses of the eyes and upper extremities of spine surgeons are exposed to considerably higher levels of external radiation (or ionizing radiation) rather than the parts of the body protected by a lead apron. The results of some studies indicate that effective radiation doses for spine surgeons may exceed the annual limits set by the International Commission on Radiological Protection

(ICRP), and the incidence of malignant neoplasms among orthopaedic traumatologist is higher than among other doctors [10].

There is a significant insufficiency of research in the Russian Federation concerning the distribution and magnitude of doses received by surgeons during spine surgery using modern intraoperative radiological control tools [11]. In practice, most surgical hospitals do not provide their specialists with all the necessary personal protective equipment, and sometimes IDM is not performed at all.

All of the above factors determine the relevance of this study, which aims to develop guidelines for radiation protection and IDM for spine surgeons.

The objective is to determine the radiation doses of surgeons performing spinal stabilization surgeries using fluoroscopy.

Design: a prospective study, description of case series.

Material and Methods

A study of radiation exposure among spine surgeons was conducted at the

Department of Neurosurgery of the S.M. Kirov Military Medical Academy (St. Petersburg) in collaboration with the St. Petersburg Research Institute of Radiation Hygiene n.a. Prof. P.V. Ramzaev from January to June 2024. The spine stabilization techniques most commonly associated with dose exposure, such as percutaneous transpedicular fixation (PTF) and percutaneous kyphoplasty (PKP), were selected for the study.

Inclusion criteria: surgical procedures for degenerative spinal conditions (levels T10 to S1) using the PTF or PKP technique; number of fixed vertebrae is not more than 4 (3 segments/no more than 8 screws); number of augmented vertebrae is not more than two.

Exclusion criteria: cases associated with a significant increase in radiation dose (combination of PTF and augmentation, repositioning of pedicle screws because of unacceptable malposition detected during serial radiography).

In accordance with the surgical procedure, two study groups were identified. The first group ($n = 11$) consisted of cases of stabilization surgery performed using the PTF technique. The second group included two series of five surgical procedures ($n = 10$) performed using the PKP technique.

In the PTF group, the Zeilm Vision RFD mobile angiography system was used for intraoperative radiological navigation, with radiation settings adjusted automatically based on the patient's physical features. The mean values of voltage and current at the anode of the roentgen tube were 87.6 kV and 13.1 mA, respectively.

In the PKP group, bone reposition was performed through a unilateral transpedicular approach using an inflatable steerable balloon catheter placed in the middle of the injured vertebral body. The radiation parameters were standard and were provided by the Vertebro DR factory test protocol. The voltage and current values at the roentgen tube anode were 71.3 kV and 108.0 mA, respectively.

The effective doses of radiation and equivalent doses of radiation to the lenses of the eyes and skin of the hands of

spine surgeons were evaluated. Furthermore, the time spent on the transpedicular metal osteosynthesis stage was analyzed. Treatment outcomes, screw placement, and the presence of bone cement migration beyond the vertebral bodies were not analyzed in this study.

The radiation doses received by specialists, in accordance with the guidelines for monitoring radiation doses received by specialists (hereinafter referred to as MU 2.6.1.3015-12) [4], were determined based on operational values using individual dosimeters. The operational value for the IDM of external radiation is the individual dose equivalent – $HP(d)$. The value of parameter d (mm), which defines the requirements for an individual external radiation dosimeter, as well as the position of the dosimeter on the staff member's body, is determined by the equivalent of its standardized value. In this study, three types of thermoluminescent dosimeters were used as measuring devices (Fig.).

1) DTU-01 – thermoluminescent dosimeters for measuring the individual equivalent dose at a depth of 10 mm – $HP(10)$; their readings were used to calculate the effective dose of radiation exposure for specialists. Since spine surgeons are classified as staff who work in areas of heterogeneous radiation (in particular, due to wearing radiation protective clothing), readings from two individual dosimeters, $HP(10)$, were used, which were placed above the protective apron on the collar of the gown and below the protective apron at chest level.

2) Eye-D – thermoluminescent dosimeters for measuring the individual dose equivalent of the eye lens at a depth of 3 mm – $HP(3)$. This measured value is a conservative assessment of the equivalent radiation dose to the lens. During measurements, the dosimeter was placed as close to the eyes as possible, yet not to interfere with the surgery.

3) Finger Ring Type G – thermoluminescent dosimeters that measure the individual equivalent dose of the fingers in the basal layers at a depth of 0.07 mm – $HP(0.07)$ and allow the equivalent dose of external skin exposure to be evaluated.

Dosimeters on the bodies of the surgeon and assistant were placed in accordance with the recommendations of MU 2.6.1.3015-12 (Fig.) [4]. Radiation safety during surgeries was ensured by individual radiation protective equipment (apron, collar) with an attenuation coefficient of 0.25. Radiation protective gloves and spectacles were not used during the study. During puncture kyphoplasty, the radiation doses received by one surgeon were evaluated.

The ambient radiation error recorded by dosimeters during the months-long study was allowed for. The DTU-01 ambient dosimeter, $HP(10)$, was placed outside the radiation area for the duration of the surgery.

For calculation of effective radiation doses, the formula recommended by MU 2.6.1.3015-12 was used, regardless of the anode voltage, apron characteristics, and the availability of a protective collar [4]:

$$E = 0.6 H(10)_{\text{chest, under}} + 0.025 H(10)_{\text{collar, above}},$$

where “ $H(10)_{\text{chest, under}}$ ” is the dose (mSv) recorded by a dosimeter located on the chest under a protective apron, and “ $H(10)_{\text{collar, above}}$ ” is the dose (mSv) recorded by a dosimeter placed above the apron on the collar of the gown or on the hair cover.

The device support for the two groups of surgeries was different. Zeilm Vision RFD mobile angiography system was used for PTF, and Siemens Artis Q angiography system was used for PKP.

The study findings were entered into an electronic database using Microsoft Excel 2007 software. Statistical data processing was performed using Statistica for Windows 10.0 software (StatSoft Inc., USA) in accordance with recommendations for statistical analysis of biomedical research findings.

Results

Dose study for PTF

The main characteristics of the surgeries performed are given in Table 1. The median radiation time was 69 seconds [interquartile range: 66; 73]. The median time spent on the placement of the instrumentation was 69 min [interquartile range: 65.0; 72.5], and the procedure

for placing one screw required a mean of 13.3 min [95% confidence interval: 12.58; 13.62].

The dosimetric parameters obtained by the surgical team are listed in Table 2.

During the calculation of effective radiation doses, values equal to the sensitivity threshold of the DTU-1 dosimeter (0.05 mSv) were used for the dose values on the chest under the apron.

The insignificant differences in the obtained values of the equivalent dose in the lenses of the eyes of the surgeon and assistant are explained by their equidistance from the irradiated area of the patient's body as a source of scattered radiation. The difference in equivalent dose on the skin of the hands (more than 6.5 times) is explained by the fact that transpedicular placement of puncture needles into the vertebrae was performed only by the surgeon under the control (in direct and lateral planes) of fluoroscopy. The relatively high radiation exposure levels for the hands are associated with the fact that, during direct view fluoroscopy, the surgeon's hands were occasionally exposed to the direct radiation beam. This also explains the higher effective radiation dose and dose above the surgeon's apron compared to the assistant. To reduce radiation exposure during lateral radiological views, the surgeon was placed directly opposite the emitter, as it is known that the radiation dose on the staff is largely formed by radiation scattered from the patient's body, and its level is much higher on the side of the radiation beam entrance because of backscattering [12].

Dose study for PKP

The results of dosimetric monitoring of surgeons in the PKP group are given in Table 3. The median radiation time was 508 s [interquartile range: 492.0; 590.5]. In both series of surgeries, depending on the radiological plane, the radiation source was placed under the operating table or on the opposite side from the surgeon.

Depending on the characteristics of the bone cement delivery systems, the surgeon's ability to keep a distance from the radiation source varied, which probably explains the differences in the doses

above the apron and in the eye area in the two series of studies. The total effective radiation dose received by the surgeon during 10 surgeries, calculated using the estimated method, was 0.09 mSv.

Discussion

In accordance with the regulatory documents of the Russian Federation, when monitoring doses for staff with low dose differences across the body, an individual dosimeter is placed at chest level. A dosimeter calibrated to measure the individual equivalent dose Hp(10) is used for this purpose. It is believed that in this case, its readings reflect effective doses of radiation exposure to humans [4–6]. Yet, this study confirms the fact of high dose difference across the body of a spine surgeon. For medical staff being in a sharply heterogeneous radiation field and working with a roentgen tube voltage from 40 to 120 kV in a protective apron because of working conditions, the technique of individual dose

assessment must be IDM. Thus, they must be provided with at least two personal dosimeters, placed over the protective apron on the gown's collar or on a cap and on the chest under the protective apron. The equation above is used to estimate effective radiation doses [4].

According to the results of the study, it was established that the effective radiation doses received by spine surgeons during stabilization procedure on the spine under radiological control (PTF and PKP) did not exceed 0.01 mSv. To achieve the recommended annual dose limit of 20 mSv, a specialist would need to perform around 2,000 such procedures, which is certainly impossible in practice. Nevertheless, it should be considered that working at the maximum permissible threshold values is extremely hazardous because of individual radiosensitivity and the probability of developing deterministic and stochastic effects of ionizing radiation. For this reason, it is important to achieve dose limits not exceeding 5 mSv per year. For instance, MU 2.6.1.3015-12 specifies that dose lim-



Fig.

Placement of dosimeters on the body of a surgeon and an assistant: 1 – dosimeter DTU-01, Hp(10), located above a radiation protective apron; 2 – dosimeter DTU-01, Hp(10), located under a radiation protective apron; 3 – individual dosimeter Eye-D, Hp(3); 4 – individual dosimeter Finger Ring Type G, Hp(0.07) on the hand

Table 1

Main characteristics of surgical interventions performed using the percutaneous transpedicular fixation technique

Level	Number of screws, pcs.	Radiation duration, sec	Metal osteosynthesis duration, min
T11–T12, L2	6	72	65
T11–L1	5	71	74
L5–S1	4	65	63
T6–T8	4	67	69
L1–L3	5	83	71
T12–L2	6	69	68
L4–L5	4	74	64
L3–L5	6	60	84
L3–L5	6	67	77
L4–S1	6	65	65
T11–L1	6	76	70
Total	58	769	770

Table 2

Dosimetric parameters of a surgical team during percutaneous transpedicular fixation (values accumulated over 11 surgeries)

Dosimetric parameter	Surgeon, mSv	Assistant, mSv
Hp(10) under the apron	<0.05	<0.05
Hp(10) above the apron	1.7	0.95
Effective dose	0.07	0.05
Hp(3) lens of the eye	1.2	1.1
Hp(0.07) skin of hands	11.96	1.73

Hp — individual dose equivalent.

Table 3

Dosimetric parameters measured for a surgeon during puncture kyphoplasty (total values for 10 surgeries in two series)

Dosimetric parameter	Series I, mSv	Series II, mSv
Hp(10) under the apron	0.01	0.02
Hp(10) above the apron	1.12	1.78
Effective dose	0.03	0.05
Hp(3) lens of the eye	0.56	1.89
Hp(0.07) skin of hands	3.77	1.79

Hp — individual dose equivalent.

its, as well as permissible exposure levels for Group B specialists, should be equal to 1/4 of the corresponding values for Group A specialists [4]. In this case, the annual dose limit for a spinal surgeon is achieved by performing 500 such surgeries. Certainly, it is improbable that a single specialist would perform such a

number of surgeries within the specified period. According to the effective radiation dose, these spine surgeries should be considered safe for the surgeon, provided that the radiation exposure is of a comparable level. According to the literature, protecting the surgeon with an apron reduces the dose by 20–50 times [7].

In the course of IDM for staff working in a sharply heterogeneous radiation field (interventional radiologists, spine surgeons, etc.), in addition to effective radiation doses, the equivalent dose to individual body parts should also be evaluated. According to the ICRP guidelines, attention is focused on the unpredictability of adverse effects caused by prolonged (years) extremely uneven exposure of organs or tissues [10, 13].

The data from previous studies show that when evaluating the potential radiation hazard to the health of operating room staff, the radiation doses to the lenses are of primary significance [14]. Both the International Atomic Energy Agency (IAEA) document and the 139 ICRP publications cite the findings of a study showing that the incidence of lens opacity (radiation cataracts) among interventional radiologists is 4–5 times higher than among non-irradiated individuals in the control group [10, 15, 16]. According to MU 2.6.1.3015-12, which is currently applicable in the Russian Federation, the equivalent dose in the lens should not exceed 150 mSv per year [6]. Nonetheless, in the IAEA safety standard GSR Part 3, the equivalent dose limit for the lens has been stipulated as 20 mSv/year. According to our findings, the equivalent radiation dose to the lenses of a spine surgeon performing 10 kyphoplasty procedures may reach 2.45 mSv. Following the guidelines of IAEA GSR Part 3, surgeons are advised not to perform more than 82 such surgeries per year without wearing protective spectacles.

Unlike interventional radiologists, spine surgeons are concerned with the doses received by the skin of the hands exposed to direct radiation beams [7, 8]. Fujibayashi et al. [17] compared the condition of the nails and skin of the first finger of the dominant hand in spine surgeons with a control group to study the effects of long-term exposure to low doses of ionizing radiation. As a result of the study, a tendency toward the development of contact dermatitis, melanonychia, and nail bed erosion among spine surgeons was established. ICRP and MU 2.6.1.3015-12 establish the maximum

equivalent dose of radiation exposure to the skin of the hands at 500 mSv per year [4, 10]. According to our data, the total radiation exposure dose to the hands of a surgeon who performed 21 stabilization procedures (PTF and PKP) was 17.52 mSv. If a safe radiation level of 1/4 of the recommended dose is targeted, the maximum number of such surgeries per year without the use of protective gloves would be 150. However, Yamashita et al. [13] report an equivalent dose of 368 mSv recorded on an individual wrist dosimeter during 52 surgeries performed by one surgeon over a 3-month period!

The foregoing equivalent dose values obtained in the study do not fully account for protection techniques that can reduce the exposure of medical staff to radiation. These include distance, shielding, and time.

Scattering from the side where the beam exit the patient is less intense than backscattering from the beam entry side, since the patient's body absorbs 80 to 99% of the primary outgoing radiation [12]. The position of the surgeon on the detector side, compared to the position on the emitter side, allows the dose to be reduced by approximately 6 times [18].

The efficiency of protective eyewear has been demonstrated in a previously published study [19]. Radiation-protective eyewear can reduce the dose of radiation exposure to the lens fivefold, depending on the area of the protective lens and its distance from the eyes. The probability of scattered radiation “flowing” under the glass from the sides and underneath is minimized by the special design of the glasses, which fit tightly to the face on all sides [9].

Exposure of the skin of the hands is minimized by wearing protective gloves (37%), and the use of a clamp or any oth-

er instrument that secures the Jamshidi needle reduces the dose of exposure to the hands by 65% [20].

A protective screen (shield) ensures radiation protection for the entire body of operating room staff (effective dose <5 µSv at a distance of 2.5 m from the radiation source during a month of stabilization surgeries on the spine) [19]. Although the benefits of shielding are clear, it should be noted that certain procedures require the surgeon to be placed directly at the source of the radiation. Moreover, the placement of a protective screen in the operating room is considerably complicated by the large number of surgical room specifications, some of which should be complied with during the initial stages of design and construction [18].

One of the relevant factors for dose reduction is the radiation time, which depends on the experience of the specialist performing surgeries with radiographic guidance [20]. The mean time required to place one pedicle screw in our study corresponds to the data reported in the global literature [21–24].

Conclusion

During the study, it was found that spine surgeons (neurosurgeons, traumatologists) performing PTF and PKP under fluoroscopy at acceptable effective radiation doses experience a high dose difference across the body, associated with the need for manual actions close to the source of ionizing radiation and the wearing of radiation protective clothing. This fact may increase the risk of stochastic effects developing in the long-term perspective.

Therefore, the following conclusions can be drawn:

1) the effective radiation dose to the surgeon performing stabilization surgery on the spine under fluoroscopy, provided that he or she is wearing a radiation protective apron, does not exceed 0.01 mSv; this complies with the recommended radiation exposure limits for operating room staff, depending on the number of surgeries performed per year;

2) the equivalent radiation dose to the lenses and skin of the hands of a spine surgeon can reach 0.25 mSv and 1.1 mSv, respectively, per surgery. The safe radiation exposure level will be surpassed after performing approximately 150 percutaneous transpedicular fixations or 82 kyphoplasties, excluding other procedures performed under radiographic guidance. The maximum number of surgeries can be increased by using personal protective equipment for the surgeon's eyes and hands and by using intraoperative CT navigation;

3) specificity of the work of spine surgeons in radiation fields with sharp dose differences across the body requires the development of guidelines and requirements for radiation protection and radiation dose monitoring for a given group of medical staff.

Limitations of the study. The limitations of the study are associated with the small number of follow-ups. The study did not assess the efficacy of additional personal protective devices, such as radiation-protective eyewear, caps, gloves, and shields.

The study had no sponsors. The authors declare that they have no conflict of interest.

The study was approved by the local ethics committee of the institution.

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Address correspondence to:

Kravtsov Maksim Nikolayevich
Research Institute of Emergency Medicine n.a. I.I. Dzhanelidze,
3 Budapeshtskaya str., St. Petersburg, 192242, Russia,
neuromax@mail.ru

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Maxim Valerievich Kubasov, neurosurgeon of the Emergency Department of the Medical Diagnostic Center, S.M. Kirov Military Medical Academy, 6 Akademika Lebedeva str., St. Petersburg, 194044, Russia, eLibrary SPIN: 8497-0248, ORCID: 0009-0002-5101-1925, kbasov-maxim.kbasov@yandex.ru;
Maksim Nikolayevich Kravtsov, DMSc, senior lecturer of the Department of Neurosurgery, S.M. Kirov Military Medical Academy, 6 Akademika Lebedeva str., St. Petersburg, 194044, Russia; Head of the Department of Neurosurgery, Research Institute of Emergency Medicine n.a. I.I. Dzhanelidze, 3 Budapeshtskaya str., St. Petersburg, 192242, Russia; Associate Professor of the Department of Neurosurgery n.a. Prof. A.L. Polenov, North-Western State Medical University n. a. I.I. Mechnikov, 41 Kirochnaya str., St. Petersburg, 191015, Russia, eLibrary SPIN: 2742-6397, ORCID: 0000-0003-2486-6995, neuromax@mail.ru;
Svetlana Sergeyevna Sarycheva, PhD in Biology, senior researcher, Laboratory of Radiation Hygiene of Medical Organizations, St. Petersburg Research Institute of Radiation Hygiene n.a. Prof. P.V. Ramzaev, 8 Mira str., St. Petersburg, 197101, Russia, eLibrary SPIN: 5132-1416, ORCID: 0000-0002-4493-0280, svetlana2003@mail.ru;
Ekaterina Nikolayevna Shleenkova, junior researcher, Radiation Control Laboratory, St. Petersburg Research Institute of Radiation Hygiene n.a. Prof. P.V. Ramzaev, 8 Mira str., St. Petersburg, 197101, Russia, eLibrary SPIN: 3712-6325, ORCID: 0009-0006-6391-1639, esleenkova@mail.ru;
Dmitry Vladimirovich Svistov, MD, PhD, associate professor, Head of the Department of Neurosurgery, S.M. Kirov Military Medical Academy, 6 Akademika Lebedeva str., St. Petersburg, 194044, Russia, eLibrary SPIN: 3184-5590, ORCID: 0000-0002-3922-9887, dsvistov@mail.ru.

