Perioperative Measurement of Radiation Exposure to Radiation-Sensitive Organs of Patients Undergoing Lumbar Surgeries Using a Thermoluminescent Dosimeter

Xin Chen[1], *Youdong Song*[1], *Zheng Li*[1], *Suming Luo*[2], *Baorong Yue*[2], *Hui Xu*[2], *Zhijian He*[2], *Zhinan Ren*[1], *Derong Xu*[1], *Shugang Li*[1]

■ OBJECTIVE: **To introduce a method of accurately measuring the equivalent dose received by radiation-sensitive organs using the thermoluminescent dosimeter (TLD) and to provide reference values for future studies associated with radiation protection in patients undergoing lumbar spine surgeries.**

■ METHODS: **After careful selection and preparation, TLD chips were used to obtain measurements from the eyes, thyroid glands, breasts, and gonads of 20 patients undergoing lumbar spine surgeries. The results were obtained via air kerma conversion-related calculations.**

■ RESULTS: **The overall radiation exposures absorbed perioperatively by the eyes, thyroid glands, right breasts, left breasts, right ovaries, left ovaries, and testes were 0.41 $\pm$ 0.13, 1.43 $\pm$ 0.45, 6.95 $\pm$ 3.63, 9.50 $\pm$ 6.14, 29.86 $\pm$ 28.62, 23.47 $\pm$ 22.10, and 5.41 $\pm$ 1.86 mSv, respectively. A single computed tomography (CT) scan contributed to more than 75% of the overall dose received regardless of the position used.**

■ CONCLUSIONS: **Patients received significantly higher radiation doses from CT scans than from regular digital radiograph examinations. These radiation doses were concentrated in the regional area of scanning. Our results indicate the necessity and benefits of radiation protection measures, especially for the organs researched herein, when patients undergoing lumbar surgeries require radiographic diagnostic examinations.**

INTRODUCTION

Radiation-associated imaging techniques, such as radiographic imaging and computed tomography (CT) scan, are indispensable components of the perioperative management of lumbar spine surgeries, which require preoperative assessments, intraoperative fluoroscopic guidance, and postoperative evaluations. However, the ionizing effects of considerable radiation exposure during these procedures could be potentially hazardous for patients. Major concerns have been raised about the harmful effects of these examinations on sensitive organs, such as lenses, thyroid glands, breasts, and gonad glands.[1-7] In general, the radioactive ionizing effects exerted on human bodies can be categorized into stochastic effects and deterministic effects.[8] Stochastic effects indicate the probability of the ionizing radiation inducing malignant tumors or causing genetic modifications but do not provide a measure of severity. Notably, no thresholds exist under such circumstances. On the other hand, the severity of impairments or injuries to specific tissues or organs increases with increasing doses of absorbed radiation. Such effects occur only above certain thresholds and contribute to deterministic effects. Both effects are dependent on the dose being absorbed. Attempts should therefore be made to obtain the most valuable clinical results while minimizing radiation exposure when these examinations are warranted. In addition, more attention should be paid to radiation protection techniques for health care professionals and patients.[9-12]

Most hospitals in China have not implemented sufficient effective protective measures, therefore exposing patients to radioactive fields. Accurate measurement of the dosages absorbed by patients in different settings would lay the groundwork for radiation protection studies.[1,8,12-14] To date, we have yet to identify

Key words
- Air kerma
- Organs
- Radiation
- Radiologic protection
- Spine

Abbreviations and Acronyms
CT: Computed tomography
DR: Digital radiograph
ICRP: International Commission on Radiological Protection
TLD: Thermoluminescent dosimeter

From the [1]Department of Orthopedics, Peking Union Medical College Hospital, Chinese Academy of Medical Sciences, Beijing; and the [2]National Institute for Radiological Protection, Chinese Center for Disease Control and Prevention, Dewai, Beijing, P.R. China

To whom correspondence should be addressed: Shugang Li, M.D. [E-mail: lishugangpumc@163.com]

Xin Chen, Youdong Song, and Zheng Li are co—first authors.

Citation: World Neurosurg. (2018). https://doi.org/10.1016/j.wneu.2018.06.104

Journal homepage: www.WORLDNEUROSURGERY.org

Available online: www.sciencedirect.com

any study that has measured radiation dosages perioperatively in patients undergoing lumbar spine surgeries.

We selected 20 patients undergoing lumbar spine surgeries to investigate the doses of radiation absorbed by the radiation-sensitive organs. The aim of our study was to introduce a method of accurately measuring the absorbed dose of radiation-sensitive organs based on application of the thermoluminescent dosimeter (TLD) and to provide reference values for future studies associated with radiation protection.

MATERIALS AND METHODS

TLD Stability and Repeatability Test

We used the TLD-2000C (LiF:Mg,Cu,P [Conqueror Corporation, Beijing, China]) as the measurement tool in our study. This type of TLD shows a good photon energy response and has been proven to be suitable for measurements in radiology. The detection limit for the TLD was 10^{-7} Gy.[8,15,16] The TLD chips were stored at room temperature for 12 hours before use. Then, all the TLDs to be tested were annealed at precisely 240°C for 10 minutes in the TLD 2000B Precision Annealing Furnace (Conqueror Corporation). After annealing, the TLD chips were exposed to a homogenous 60 Co gamma radiation field at a dose of 100 cGy via radiation therapy equipment (Institute of Medical Equipment, Shandong, China).

Single TLD Calibration Factor Test

After all the TLD chips were irradiated in a homogenous radiation field at a dose of 100 cGy, readings were obtained via the Harshaw 3500 TLD reader (Thermo Fisher Scientific, Monrovia, California, USA). The average TLD reading of all chips was divided by each TLD reading to obtain calibration factor values. The process was repeated 3 times, and an average TLD calibration factor for each chip was calculated. The chips with a calibration factor exceeding 3% were eliminated from our study, and the rest were considered qualified TLD chips for other tests.

TLD Fading Correction Factor Test

We randomly selected 12 qualified chips and exposed them to a homogenous radiation field at a dose of 100 cGy after annealing. Then, the TLD readings at different fading times were recorded (Table 1).

Table 1. Thermoluminescent Dosimeter Fading Correction Factor Test

Time (hours)	TLD Reading (μC)	Fading Correction Factor
0.5	11.25	1.000
4	11.26	1.001
24	11.28	1.003
48	11.34	1.008
72	11.13	0.99
96	11.29	1.004
120	11.32	1.067
144	11.35	1001
168	11.38	1.012
720	11.00	0.979

Twelve chips were randomly selected from the qualified chips and exposed under a homogenous radiation field at a dose of 100 cGy after annealing.
TLD, thermoluminescent dosimeter.

Ionization Chamber Marking

To obtain reliable results, the accuracy of all measurement instruments must be verified. The ionization chambers of the radiograph equipment and CT scanner used in our study were calibrated at the National Institute of Metrology of China.[8] This process is also known as ionization chamber marking.

Air Kerma Standardized Dose Curve

According to the International Commission on Radiological Protection (ICRP), the doses absorbed by organs from exterior radiation cannot be measured directly but rather only via calculation using the air kerma conversion coefficient.[17] Therefore, establishing an air kerma dose curve is imperative when attempting to accurately measure the equivalent dose for a specific organ. We established 2 independent dose curves for the CT and radiograph equipment.

The CT tube was first placed in a fixed position, and an anthropomorphic phantom was then positioned on the CT bed. Next, ionization chamber 1 (model 10X6-6, connected to radiation monitor controller model 9096 [Radcal Corporation, Monrovia, California, USA]) was positioned on a relatively flat area of the phantom's abdomen. The ionization chamber was consecutively irradiated at doses of 0.2, 0.4, 0.6, 0.8, 1.0, 5.0, 10.0, 20.0, 30.0, 40.0, 50.0, and 70.0 mGy under a tube potential of 120 KV. The qualified TLD chips were irradiated under exactly the same conditions and at the same position, and readings were obtained. Finally, an air kerma standardized curve was generated by plotting the TLD readings against the ionization chamber readings via the least square fitting method (Figure 1).

In a similar manner, air kerma standardized curves for the radiograph equipment were established. Ionization chamber 2 (model 10X5-60, connected to radiation monitor controller model 9010 [Radcal Corporation]) was irradiated at digital radiograph (DR) potential values of 40, 60, 70, 80, 100, and 120 KV. Again, a set of TLD chips was irradiated and measured under the same circumstances. The air kerma standardized curve for DR was then established by plotting the TLD readings against the ionization chamber readings using the least square fitting method (Figure 2).

TLD Positioning on Patients

Patients who were chosen to undergo lumbar spinal surgeries and provided informed consent were recruited for our study. In this study, we measured radiation exposure during the entire perioperative process, including preoperative radiograph and CT scan, intraoperative navigation radiograph, and postoperative radiograph. All patients in our study underwent a total of 7 kinds of radiographic examination (Table 2), during which all lateral