



The Utility and Feasibility of Smart Glasses in Spine Surgery: Minimizing Radiation Exposure During Percutaneous Pedicle Screw Insertion

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(Citation)

Neurospine, 21(2):432-439

(Issue Date)

2024-06

(Resource Type)

journal article

(Version)

Version of Record

(Rights)

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(URL)

<https://hdl.handle.net/20.500.14094/0100490459>





Original Article

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Received: January 22, 2024

Revised: February 26, 2024

Accepted: March 17, 2024

See the commentary on “The Utility and Feasibility of Smart Glasses in Spine Surgery: Minimizing Radiation Exposure During Percutaneous Pedicle Screw Insertion” via <https://doi.org/10.14245/ns.2448568.284>.



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The Utility and Feasibility of Smart Glasses in Spine Surgery: Minimizing Radiation Exposure During Percutaneous Pedicle Screw Insertion

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Objective: Spine surgeons are often at risk of radiation exposure due to intraoperative fluoroscopy, leading to health concerns such as carcinogenesis. This is due to the increasing use of percutaneous pedicle screw (PPS) in spinal surgeries, resulting from the widespread adoption of minimally invasive spine stabilization. This study aimed to elucidate the effectiveness of smart glasses (SG) in PPS insertion under fluoroscopy.

Methods: SG were used as an alternative screen for fluoroscopic images. Operators A (2-year experience in spine surgery) and B (9-year experience) inserted the PPS into the bilateral L1–5 pedicles of the lumbar model bone under fluoroscopic guidance, repeating this procedure twice with and without SG (groups SG and N-SG, respectively). Each vertebral body's insertion time, radiation dose, and radiation exposure time were measured, and the deviation in screw trajectories was evaluated.

Results: The groups SG and N-SG showed no significant difference in insertion time for the overall procedure and each operator. However, group SG had a significantly shorter radiation exposure time than group N-SG for the overall procedure (109.1 ± 43.5 seconds vs. 150.9 ± 38.7 seconds; $p = 0.003$) and operator A (100.0 ± 29.0 seconds vs. 157.9 ± 42.8 seconds; $p = 0.003$). The radiation dose was also significantly lower in group SG than in group N-SG for the overall procedure (1.3 ± 0.6 mGy vs. 1.7 ± 0.5 mGy; $p = 0.023$) and operator A (1.2 ± 0.4 mGy vs. 1.8 ± 0.5 mGy; $p = 0.013$). The 2 groups showed no significant difference in screw deviation.

Conclusion: The application of SG in fluoroscopic imaging for PPS insertion holds potential as a useful method for reducing radiation exposure.

Keywords: Smart glasses, Pedicle screw, Fluoroscopy, Augmented reality, Radiation exposure

INTRODUCTION

Spine surgeons are at risk of radiation exposure owing to the use of fluoroscopy during surgery, fracture or dislocation repositioning, and administering block injections. Exposure to ionizing radiation is associated with various health risks, including an increased risk of cancer and skin disorders of the fingers.¹⁻⁴ There is an increasing concern about radiation exposure, espe-

cially in the field of spine surgery, due to the widespread use of minimally invasive spine stabilization,⁵ which frequently requires percutaneous pedicle screw (PPS) insertion under fluoroscopic guidance.^{6,7} Protective measures, including lead aprons, thyroid collars, and gloves, can reduce radiation exposure but cannot eliminate its risk. In addition, prolonged use of these protective gear can lead to physical discomfort and fatigue, directly affecting the surgeon's performance. Therefore,

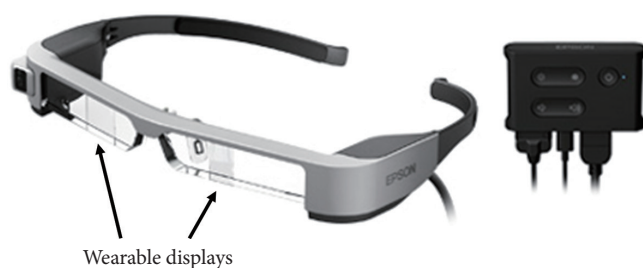


Fig. 1. The MOVERIO smart glasses (SG) used in this study. This SG is a wearable device manufactured by Epson Co., Ltd. (Tokyo, Japan). It features a wearable display for each eye, allowing users to project fluoroscopic images onto the wearable display by connecting the SG to a fluoroscopic monitor.

developing new methods to reduce radiation exposure is crucial in spinal surgery. Attention has shifted to wearable technology as a relatively easily implementable solution to reduce radiation exposure in spinal surgeries.

Wearable technology, represented by smart glasses (SG), has entered the medical field and is expected to significantly impact surgery in various specialties.⁸⁻¹¹ Since the launch of Google Glass (Google Inc., Mountain View, CA, USA) in 2013, various types of SG have been released and have become commonly used for medical purposes, including education, surgery navigation, and monitoring vital signs.^{12,13} MOVERIO (EPSON Co., Ltd., Tokyo, Japan) (Fig. 1)—another pair of SG—displays images from the monitoring screen to a wearable display. One valuable application of SG is in surgical procedures performed under fluoroscopic guidance. The frequent diversion of a surgeon's attention from the operative field to the fluoroscopic monitor can decrease procedural accuracy. Therefore, SG can display fluoroscopic images on wearable displays, and surgeons can perform procedures while keeping their eyes on the operative field. This technology has been reported to reduce radiation exposure and improve screw insertion accuracy under fluoroscopic guidance in trauma surgery.^{6,7} However, no reports have addressed the impact of SG on reducing radiation exposure and improving screwing accuracy in the spinal region.

We hypothesized that PPS insertion with SG would reduce surgeons' radiation exposure and improve screw insertion accuracy. Therefore, this pilot study aimed to elucidate the efficacy and feasibility of SG for PPS insertion under fluoroscopic guidance.

MATERIALS AND METHODS

1. Devices

This study does not include information on human tissues,

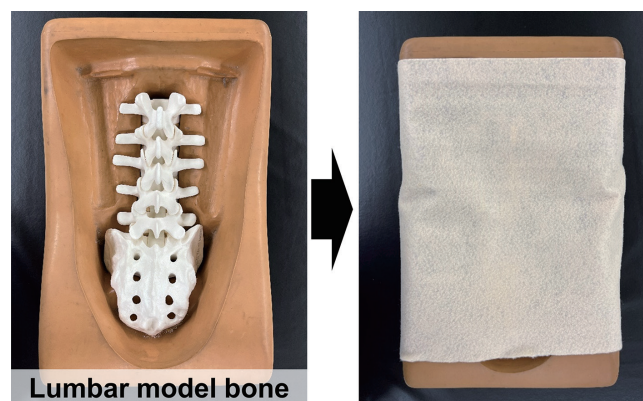


Fig. 2. A lumbar model bone. A prepared model bone was covered with cloth to simulate the surgical situation more accurately, ensuring that the model bone remained hidden from view.

materials, or patients. Therefore, ethical approval was not required. This study used the MOVERIO model BT-30E (Fig. 1) as the SG. This model has a wearable binocular HD 1,280 × 720 pixel display. The COREVISION 3D (FUJIFILM Co., Ltd., Tokyo, Japan) fluoroscopy system was used in this study. The SG and fluoroscopic monitor were connected using a cable with a high-definition multimedia interface port to project the monitor's screen onto the wearable display in real time without any noticeable time lag. The Erisma-LP MIS (Clariance Inc., Beauvais, France) PPS systems were used in this study.

2. Evaluation of PPS Insertion

First, operator A, who had 2 years of experience in spinal surgery, conducted the experiment. In total, 10 PPSs were inserted into 5 bilateral L1–5 vertebrae in one lumbar model bone (Sawbone, Sawbones Inc., Malmo, Sweden) under fluoroscopic guidance with SG (group SG). The optimal diameters and lengths of the inserted screws were selected based on the model bone's profile. The lumbar model bone was covered with a soft cloth to hide its appearance (Fig. 2). PPS insertion was performed by making a small incision in the cloth using a scalpel and inserting a hollow probe into each pedicle under fluoroscopic guidance. The operator confirmed that the probe did not deviate from the pedicle in the anteroposterior and lateral views of the fluoroscopic images. A guidewire was inserted through the probe, followed by tapping over the guidewire to create a path for the screw. Finally, a pedicle screw was inserted over the guidewire.

Similarly, 10 PPSs were inserted into another model bone using the conventional technique while watching the fluoroscopic

Table 1. The grading system used for the assessment of screw placement

| Different types of misplacement | |
|---------------------------------|---|
| Axial images (A–F) | A: Acceptably placed screw |
| | B: MCP (medial cortical perforation) grade 1 |
| | C: MCP grade 2 |
| | D: LCP (lateral cortical perforation) grade 1 |
| | E: LCP grade 2 |
| | F: ACP (anterior cortical perforation of the vertebral body) grade 1 |
| Sagittal images (G–I) | G: Acceptably placed screw |
| | H: FP (foraminal perforation) grade 1 |
| | I: EPP (endplate perforation) grade 1 |
| Detailed definitions | |
| MCP | Grade 0: Acceptable placement; screw within the pedicle medullary canal or minimal breach of medial cortex |
| | Grade 1: Partially medialized screw |
| | Grade 2: Totally medialized screw |
| LCP | Grade 0: Acceptable placement; screw within the pedicle medullary canal or minimal breach of lateral cortex |
| | Grade 1: Partially lateralized screw |
| | Grade 2: Totally lateralized screw |
| ACP | Grade 0: Acceptable placement; screw tip within the vertebral body |

monitor without using SG (group N-SG). The operator repeated this procedure twice, and 10 vertebrae with 20 PPSs were evaluated with and without SG. Operator B, with 9-year experience in spinal surgery, also performed the same series of procedures as operator A. The time required to insert 2 PPSs into each vertebra (insertion time), radiation exposure time, and radiation dose were measured. Computed tomography (CT) was performed after PPS insertion and axial or sagittal slices of the multiplanar reconstruction CT images were used to assess the presence or absence of screw deviation. The direction and amount of screw deviation were evaluated using the grading system (type A–I) by Abul-Kasim et al.¹⁴ (Table 1). Those meeting the criteria of type A and G (acceptably placed screw in either axial or sagittal images) were defined as having no deviation, while all others were defined as having a deviation (Fig. 3A and B).

3. Illustration of PPS Insertion Using SG

The operator wore a radiation protection apron, neck cover, and gloves during the procedures. When wearing the SG, the operators could perform the procedures without diverting their gaze from the surgical field (Fig. 4A). Fig. 4B illustrates the operator's actual view of PPS insertion when using the SG. Lowering the gaze allows the operator to view the surgical field, and maintaining the gaze level lets the operator view the fluoroscopic image projected on the wearable displays. This enables the op-

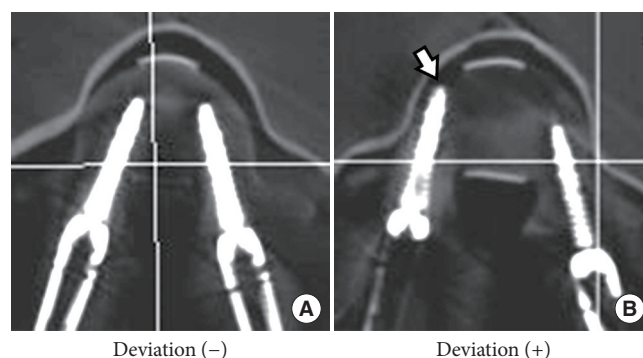


Fig. 3. Computed tomography images after pedicle screw insertion. (A) Bilateral pedicle screws were appropriately inserted in the pedicles and vertebral body without any deviation. (B) The right pedicle screw perforating outside the pedicle (arrow), leading to a determination of deviation. In this case, it was classified as type D due to the observation of a grade 1 lateral cortical perforation.

erators to confirm the fluoroscopic image and the surgical field without moving their heads. However, in the conventional method of PPS insertion without SG, the operator has to shift their gaze away from the surgical field to check the fluoroscopic monitor, necessitating head movement during the procedure (Fig. 4C).

4. Statistical Analysis

The collected data were statistically analyzed using IBM SPSS

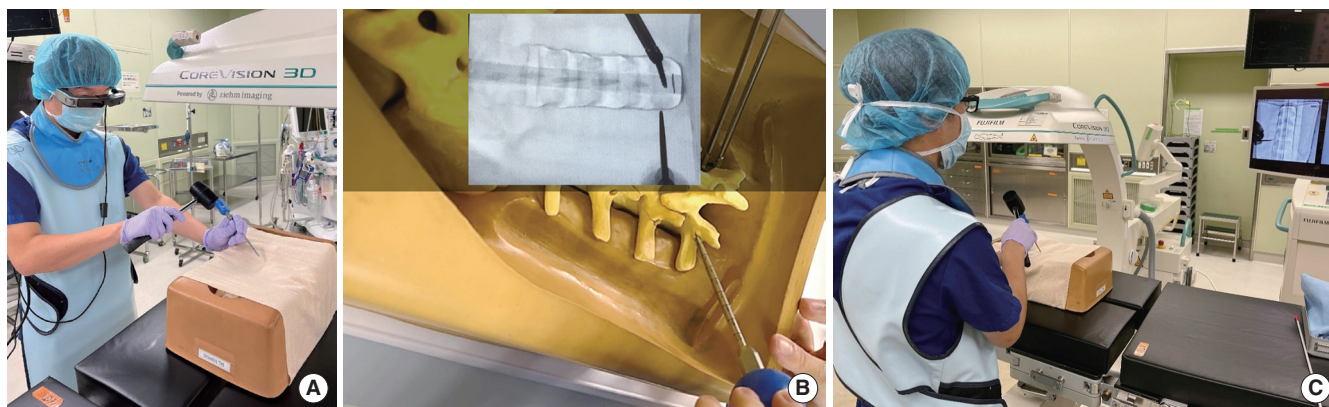


Fig. 4. Illustration of percutaneous pedicle screw insertion. (A) When wearing the smart glasses (SG) and operating, the gaze is always directed towards the surgical field, minimizing the need to move the head up and down. (B) Field-of-view while wearing the smart glasses. Surgeons can observe the fluoroscopic image or surgical field with minimal eye movements. The operator can instantly refer to the fluoroscopic image intraoperatively without moving the head. (C) Without wearing the SG, it is necessary to divert attention from the surgical field when looking at the fluoroscopic monitor.

Statistics ver. 20.0 (IBM Co., Armonk, NY, USA). The groups SG and N-SG overall and by operator comparisons of the insertion time, radiation exposure time, and radiation dose were performed using an unpaired t-test. Similarly, the chi-square test was used to compare the 2 groups for the PPS's deviation from the pedicle. All statistical tests were 2-sided, and statistical significance was set at $p < 0.05$.

RESULTS

Overall, the 2 groups showed no significant difference in insertion time (SG: 503.5 ± 144.7 seconds, N-SG: 549.4 ± 119.8 seconds; $p = 0.28$); however, radiation exposure time was significantly shorter, and radiation dose was significantly lower in group SG than group N-SG (SG: 109.1 ± 43.5 seconds, N-SG: 150.9 ± 38.7 seconds; $p = 0.003$, SG: 1.3 ± 0.6 mGy, N-SG: 1.7 ± 0.5 mGy; $p = 0.023$, respectively) (Fig. 5A). For operator A, there was no significant difference in insertion time between the 2 groups (SG: 485.2 ± 116.6 seconds, N-SG: 516.4 ± 124.6 seconds; $p = 0.57$), whereas radiation exposure time was significantly shorter, and radiation dose was also significantly lower in group SG than group N-SG (SG: 100.0 ± 29.0 seconds, N-SG: 157.9 ± 42.8 seconds; $p = 0.003$, SG: 1.2 ± 0.4 mGy, N-SG: 1.8 ± 0.5 mGy; $p = 0.013$, respectively). For operator B, the 2 groups showed no significant differences in insertion time (SG: 521.8 ± 172.9 seconds, N-SG: 582.4 ± 111.1 seconds; $p = 0.37$), radiation exposure time (SG: 118.1 ± 54.5 seconds, N-SG: 143.9 ± 34.9 seconds; $p = 0.23$), and radiation dose (SG: 1.4 ± 0.7 mGy, N-SG: 1.6 ± 0.5 mGy; $p = 0.45$) (Fig. 5B).

There was no significant difference in insertion accuracy between the 2 groups' overall procedure or by operator comparisons; however, there was a tendency for less deviation from the pedicle in group SG for operator B ($p = 0.24$) (Table 2). Regarding the details of the deviation types (Table 1), in the case of operator A, group SG had 3 instances of type B, 1 instance each of type C, D, and E, while group N-SG had 4 instances of type B and 2 instances of type C. In the case of operator B, group SG had 2 instances of type B, and group N-SG had 3 instances of type B and 3 instances of type I.

DISCUSSION

This study highlights that using SG during PPS insertion can significantly reduce radiation exposure compared with the conventional method. Furthermore, in the case of operator B, who had less experience with spinal surgeries, a greater reduction in radiation exposure was demonstrated with the use of SG.

Wearing SG minimizes the need to divert attention from the surgical field, whereas conventionally, surgeons have to check the fluoroscopic monitor during the procedure. With SG, surgeons can observe the fluoroscopic image or surgical field with minimal eye movement. This enabled stable screw insertion procedures, leading to a reduction in the fluoroscopy time of each scan, and consequently resulting in a decrease in both the total fluoroscopy time and radiation dose. Additionally, there are several reasons why SG contributed to the reduction in time under fluoroscopic operation. Firstly, the use of the wearable displays equipped in SG has been reported to reduce posture

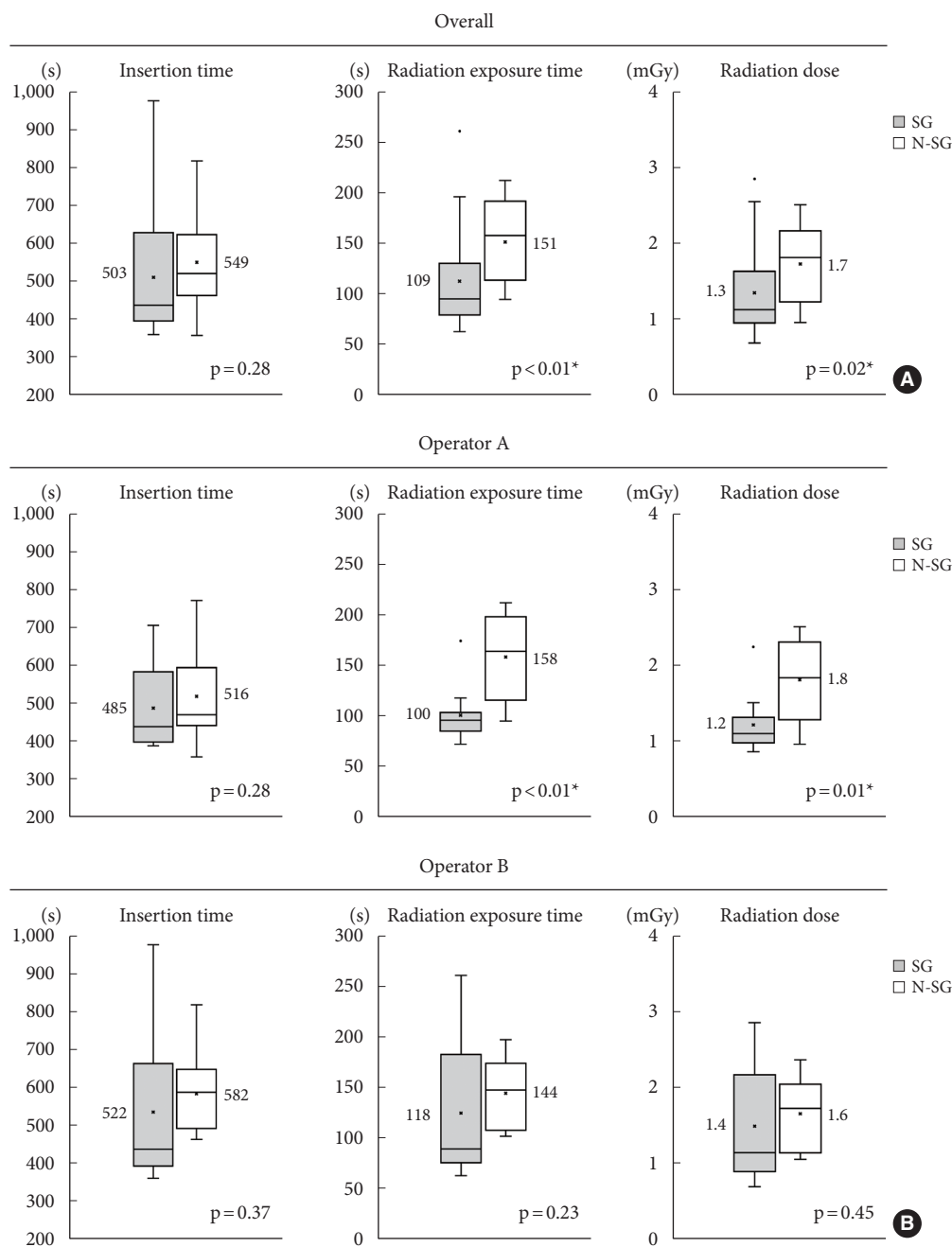


Fig. 5. Comparisons of insertion time, radiation exposure time, and radiation dose between groups smart glasses (SG) and non-SG (N-SG). (A) Comparison between groups SG and N-SG in overall insertion time, radiation exposure time, and radiation dose. Radiation exposure time was significantly shorter, and the radiation dose was significantly lower in group SG compared with group N-SG. (B) Comparison between groups SG and N-SG in insertion time, radiation exposure time, and radiation dose, stratified by operator. For operator A, group SG showed a significantly shorter radiation exposure time and a significantly lower radiation dose than group N-SG. * $p < 0.05$.

discomfort.¹⁵ This could potentially decrease fatigue during continuous screw insertion, as in our study. Furthermore, the images on the wearable displays are closer than those on a fluoroscopic monitor, allowing for a clearer view. This could have been

particularly beneficial in scenarios requiring detailed image examination, such as verifying the pedicle.

SG application has helped improve the accuracy of guidewire insertion in femoral fracture surgeries⁷ and reduce the radia-

Table 2. The comparison of screw accuracy between groups SG and N-SG overall and by operator

| Group | Overall | | | | Operator A | | | | Operator B | | | |
|-------|-----------|-----|--------------|----------|------------|-----|--------------|----------|------------|-----|--------------|----------|
| | Deviation | | Accuracy (%) | Total | Deviation | | Accuracy (%) | Total | Deviation | | Accuracy (%) | Total |
| | (+) | (-) | | | (+) | (-) | | | (+) | (-) | | |
| SG | 8 | 32 | 80 | 40 | 6 | 14 | 70 | 20 | 2 | 18 | 90 | 20 |
| N-SG | 12 | 28 | 70 | 40 | 6 | 14 | 70 | 20 | 6 | 14 | 70 | 20 |
| Total | 20 | 60 | 75 | p = 0.44 | 12 | 28 | 70 | p = 1.00 | 8 | 32 | 80 | p = 0.24 |

SG, smart glasses; N-SG, non-SG.

tion exposure of operators in hand pinning surgeries.¹⁶ The utility of SG has been reported in the trauma field^{6,7,16}; however, there are limited studies on the spinal region¹⁷⁻²⁰ and no reports addressing radiation exposure reduction. Navigation systems can also reduce radiation exposure in spine surgeries²¹; however, they are not commonly used because of their high cost and the need for additional skin incisions to place the navigation reference. Furthermore, using navigation systems may protect the surgeon and paramedical staff from radiation exposure but not to the patient. Mendelsohn reported that the radiation exposure of patients undergoing spine surgery under intraoperative CT-based navigation was approximately 2.7 times higher than that under fluoroscopic guidance.²² On the other hand, SG have the advantage of not requiring registration like navigation systems, allowing for immediate use without radiation exposure during nonsurgical procedures. In conclusion, SG constitute a low-cost and easy-to-implement option for reducing radiation exposure for medical staff and patients.

The 3 principles of radiation safety are time (minimizing the time spent near the radiation source), distance (maximizing the distance from the radiation source), and shielding (using appropriate shielding devices).²³ Therefore, performing procedures as far as possible from the irradiation field while not hindering the operator's skills is necessary in addition to using shielding devices such as lead glasses, thyroid protectors, aprons, and radiation-reducing gloves. Lead goggles exhibited the highest shielding effect when the line-of-sight was directed toward the main scattering source. This indicates that the shielding effect was maximized when the gaze was focused on the surgical field while confirming the anteroposterior image.²⁴ Consequently, when diverting the gaze from the surgical field to view the fluoroscopy monitor, there is an increased radiation exposure to the lens. Therefore, using SG to keep the operator's gaze on the surgical field, especially during surgeries that confirm the anteroposterior image, can efficiently enhance the lens's radiation protection. In actual clinical practice, continuous fluoroscopy is pri-

marily utilized in the anteroposterior view during PPS insertions. This context could further highlight the importance of SG, especially if they were equipped with x-ray shielding capabilities. However, "time" is the most effective factor among the 3 principles,¹² and unnecessary irradiation should be avoided as much as possible. As most of the radiation exposure to the operator comes from scattered radiation from the patient, measures to reduce patient exposure, such as minimizing fluoroscopy time, are often effective in reducing operator exposure. This adheres to the ALARA (As Low As Reasonably Achievable) principle, which aims to minimize a patient's radiation exposure as much as possible.^{25,26} "Time" is a parameter that can be shortened depending on the ingenuity employed during the procedure. This study demonstrated that SG application effectively reduces radiation exposure time, providing a significant benefit in minimizing the health damage caused by radiation exposure. Reducing surgical time through skill improvement is also essential in minimizing radiation exposure time. This study revealed that the effect of SG usage on reducing radiation exposure was greater for operator A, who was less experienced in spinal surgery. Inexperienced surgeons, who had to repeatedly alternate their focus between the surgical field and the fluoroscopic monitor, could achieve stable surgeries using SG without moving their heads. Therefore, using SG could bridge the gap in surgeon skill levels, which should be particularly beneficial for less-experienced surgeons.

This study has some limitations. First, the model bones could not perfectly replicate human bone structures and we were unable to use materials that closely simulate the tension and realism of living tissues to cover the model bones. This might have affected the experimental results. However, we regard this study's results as a milestone for future clinical trials. Second, the number of experiments was limited. Therefore, the challenges encountered during a single screw insertion significantly influenced the results. In the case of operator B, there was considerable variability in insertion time, radiation dose, and radiation

exposure time, especially in group SG. This variability might have masked the true significance of SG. therefore, further trials may be required to obtain sophisticated data on accuracy, reproducibility, and learning curve. Finally, the SG used in this study (MOVERIO) could not be used with radiation protection goggles, reducing the lens' protection against exposure. Low doses of radiation exposure can cause late-onset radiation cataracts²⁷; therefore, using lead-lined goggles to protect the lens has been well-established for performing procedures under fluoroscopy.²⁸⁻³⁰ However, there is a report on SG that can be attached to goggles,⁷ and this is a useful approach that can be implemented quickly. In addition, Dorey et al.²⁴ have reported on the usefulness of SG with lead-shielded lenses, and further research is necessary on the development and clinical application of SG equipped with shielding functions in the lenses.

CONCLUSION

Using SG during PPS insertion can significantly reduce radiation exposure compared with the conventional method. SG application helps minimize potential harm to healthcare professionals by reducing the time spent near the radiation source. SG application is a low-cost, easy-to-implement option for reducing radiation exposure during spinal surgery.

NOTES

Conflict of Interest: Yoshiaki Takeoka and Kohei Kuroshima endowed course (Surgical Spine, Inc., Tokyo, Japan and SMI, Inc., Nagoya, Japan). Except for that, the other authors have nothing to disclose.

Funding/Support: This study was supported by Johnson & Johnson, Inc., Tokyo, Japan.

Author Contribution: Conceptualization: YH, YT, RK, KKakutani; Data curation: YH, YT, HO, TM, MR, NK, KK, RK, KKakutani; Formal analysis: YH, YT, TY, TT, YK, KM, HO, TM, MR, NK, KKuroshima, RK, KKakutani; Funding acquisition: TY; Methodology: YH, YT, RK, KKakutani; Project administration: YH, YT, TY, TT, YK, KM, HO, TM, MR, NK, KKuroshima, RK, KKakutani; Visualization: YH; Writing – original draft: YH, YT; Writing – review & editing: YT, TY, TT, YK, KM, HO, TM, MR, NK, KKuroshima, RK, KKakutani.

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