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Evaluation of the effectiveness of intraoperative fluoroscopy and postoperative computed tomography in thoracolumbar fusion surgeries

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Abstract

Objective: This study aims to evaluate the accuracy and safety of pedicle screw placement in thoracolumbar spinal fusion surgeries. comparing intraoperative two-way fluoroscopy and postoperative computed tomography (CT), and to analyze the influence of spinal anatomy and biomechanics.

Material and methods: A retrospective cohort study was conducted on 94 patients who underwent thoracolumbar spinal fusion surgery. Demographic data including age, gender, and surgical indications were collected. Intraoperative fluoroscopy and postoperative CT images were analyzed to assess pedicle screw placement accuracy.

Results: Among the 519 pedicle screws placed, 496 (95.6%) were graded as A or B in the intraoperative fluoroscopy, whereas 23 (4.4%) were C, D, or E. Postoperative CT findings demonstrated a significant difference ($p<0.001$) in screw placement accuracy, with 483 (93.1%) screws rated as A or B. Moreover, the postoperative CT showed a higher precision in determining the screws' alignment with vertebral bodies, stability, and potential complications. The correlation between intraoperative and postoperative imaging modalities indicated substantial sensitivity (93.8%), specificity (95.6%), positive predictive value (98.8%), and negative predictive value (83.3%).

Conclusion: Postoperative CT emerges as a crucial imaging method in enhancing the success and safety of pedicle screw placement in spinal fusion surgeries.

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Introduction

Spinal fusion surgery is widely performed worldwide to treat cervical and thoracolumbar pathologies (1,2). Initially developed to address instability and deformities resulting from tuberculosis, scoliosis, and traumatic injuries, this surgical method now encompasses a broad range of indications such as spondylolisthesis, congenital or degenerative deformities, spinal tumors, and pseudarthrosis (3). The most common indication is degenerative diseases (4).

Intraoperative imaging, often utilizing fluoroscopy, is employed to enable the surgeon to clearly visualize the spine and ensure accurate placement of screws. Two-dimensional fluoroscopy is a common imaging method used to show the position and direction of pedicle screws intraoperatively (5). This method provides real-time imaging during the placement of pedicle screws. The positions and directions of pedicle screws are examined in anteroposterior and lateral views. This method is the most commonly used approach for the placement of pedicle screws. However, this method has some disadvantages. For

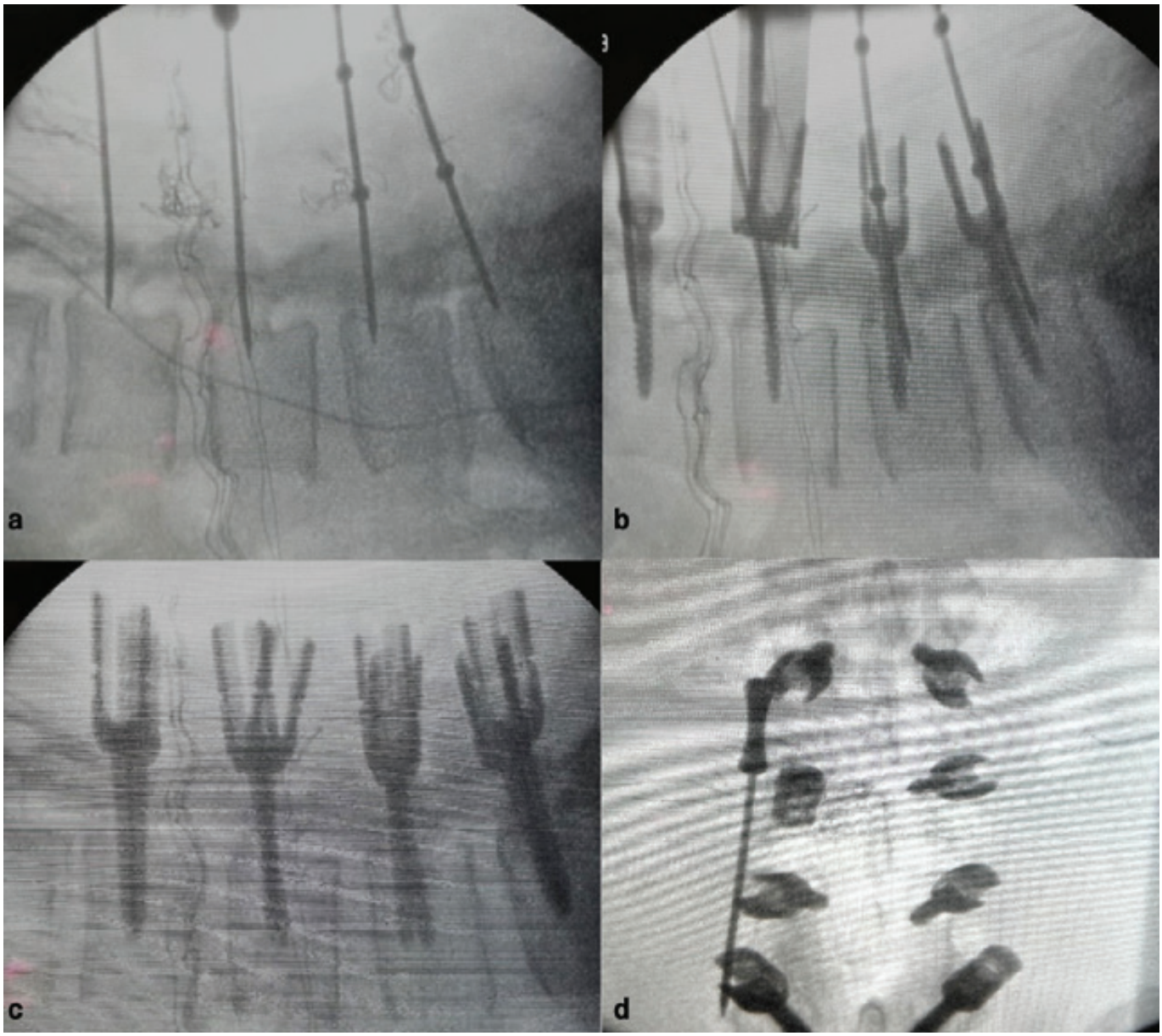

Figure 1. a. Lateral fluoroscopic image taken after placement of pedicle probes. It can be seen that the probe inserted into the L4 vertebral pedicle is at the upper border of the pedicle. During the case, the pilot hole can be relocated in this way without placing a pedicle screw. b. In the lateral fluoroscopic image taken after placement of the pedicle screws of the same side and placement of the contralateral pedicle probes, the locations of the pedicle screws were correctly evaluated. The pedicle probe placed at L5 is seen to be close to the inferior border of the pedicle. c&d. Lateral and anteroposterior fluoroscopic images taken for final evaluation after placement of pedicle screws. The pedicle screw locations were correctly assessed.

example, it may lead to radiation exposure, low image quality, incomplete visualization of pedicle screws, the necessity to move the fluoroscopy device during the placement of pedicle screws, and limitations on the surgeon's field of view during the placement of pedicle screws (6,7). However, fluoroscopy alone may not be sufficient for accurate pedicle screw placement, necessitating verification with postoperative computed tomography (CT) (8). CT provides cross-sectional imaging after the placement of pedicle screws. The positions and directions of pedicle screws are examined in axial, sagittal, and coronal views. This method is considered the gold standard for evaluating pedicle screws. This is because it displays the positions and directions of pedicle screws in three dimensions and clearly illustrates their relationship with the bone tissue (9). This method is used to identify errors in the placement of pedicle screws, complications, and the need for revision. However, this method also has some disadvantages. For example, it may lead to radiation exposure, cost, accessibility, degradation of image quality due to metal artifacts from pedicle screws, and the need for evaluation not during, but after the placement of pedicle screws (7,10).

The primary aim of this study is to evaluate the correlation between intraoperative fluoroscopy and postoperative CT in the placement of pedicle screws in thoracolumbar spinal fusion surgeries. It seeks to determine whether there are differences in the positions and directions of pedicle screws between intraoperative fluoroscopy and postoperative CT, assess the concordance of the two methods based on variables such as surgical level, patient age, gender, indication, complications, and fusion rate, and examine their respective advantages and disadvantages to assess their superiority over each other.

Materials and methods

Study population

In this study, 94 patients who underwent thoracolumbar spinal fusion surgery at a designated tertiary health center between April 2022 and May 2023 were retrospectively analyzed. Patient selection included adult patients who underwent this surgery and met the specified criteria. In this study, a comprehensive and systematic approach was adopted to collect data from patients undergoing thoracolumbar spinal fusion surgery. The data collection process focused on the intraoperative and postoperative periods of the patients, which plays a critical role in achieving the main objectives of the study.

Intraoperative fluoroscopy images

Two-way fluoroscopy images taken during each patient's surgery were collected. The images were used to assess the accuracy, angle, and depth of pedicle screw placement. Fluoroscopy images were used to analyze the decisions and techniques made during surgery. During placement of the pedicle screws, anteroposterior (AP) and lateral (LAT) images were

Table 1: Demographic data of patients undergoing thoracolumbar fusion surgery

Demographic Data (Total n=94)	**Mean ± SD / n (%)**
Age	43.7 ± 14.2
Sex	
Male	48 (51.1)
Female	46 (48.9)
Height (cm)	169.2 ± 9.1
Weight (kg)	72.4 ± 13.4
Body Mass Index (kg/m2)	25.3 ± 4.1
Surgery idications	
Spinal stenosis, spondylolisthesis and degenerative disc disease	48 (51.1)
Spinal trauma	26 (27.7)
Spinal tumor	8 (8.5)
Spinal infection	6 (6.4)
Others	6 (6.4)

taken for each vertebra. The positions and orientations of the pedicle screws were graded according to the Gertzbein and Robbins classification (A-E) based on intraoperative fluoroscopy images (11). The quality, clarity and angle of the intraoperative fluoroscopy images were also evaluated (Figure 1).

Postoperative computed tomography (CT) images

In the postoperative period, CT scans were performed in each patient and images were obtained. CT images were analyzed to assess the accuracy of the position and orientation of the pedicle screws. CT images were also used to determine the relationship between the screws and the vertebrae and surrounding tissues. Postoperative CT images of the patients were used to further evaluate the positions, orientations, depths, and relationships of the pedicle screws to adjacent structures. The positions and orientations of the pedicle screws were graded according to the Gertzbein and Robbins classification (A-E) based on the postoperative CT images (11). The compatibility of the pedicle screws with the vertebrae, stability, fatigue behavior, complications, risks and side effects were also analyzed.

Patient demographics and surgical details

Patients' age, gender, surgical indications and other health information were collected. Surgical details such as surgical techniques, instruments used, and operative time were recorded.

Clinical and radiographic results

Clinical and radiographic results obtained during the postoperative follow-up of the patients were collected. These data were used to evaluate the long-term success of pedicle screws and complications.

Statistical analysis

Patient data collected within the scope of the study were analyzed with the IBM Statistical Package for the Social Sciences (SPSS) for Windows 26.0 (IBM Corp., Armonk, NY) package program. Demographic characteristics, surgical details and clinical outcomes were summarized using descriptive statistics (mean, median, standard deviation, frequencies). Paired t-test or Wilcoxon signed rank test was used to evaluate discrepancies between intraoperative duplex fluoroscopy and postoperative CT imaging results. Sensitivity, specificity, positive predictive value (PPV) and negative predictive value (NPV) calculations were performed to assess the accuracy of each imaging technique. Chi-square or Fisher's exact tests were used to compare categorical variables (e.g. complications, fusion rates) between the two imaging techniques. Correlation or regression analysis was performed to explore associations between imaging accuracy and patient demographics or surgical variables. $p<0.001$ were considered statistically significant.

Results

The study included 94 patients who underwent thoracolumbar spinal fusion surgery. Forty-eight patients were male (51.1%) and 46 were female (48.9%). The age of the patients ranged from 18 to 65 years with a mean age of 43.7±14.2 years. The height of the patients ranged between 150 and 190 cm with a mean height of 169.2 cm. The mean body weight of the patients varied between 45 and 110 kg and the mean body weight was 72.4 kg. Body mass index ranged between 17.8 and 36.5 kg/m2 and the mean body mass index (BMI) was 25.3 kg/m2. The indications for the operation were as follows: 48 patients had undergone thoracolumbar spinal fusion surgery for spinal stenosis, spondylolisthesis and degenerative disc disease, 26 for spinal trauma, 8 for spinal tumor, 6 for spinal infection and 6 for other reasons (Table 1).

In the study, a total of 519 pedicle screws were inserted. Of these, 496 (95.6%) were grade A or B and 23 (4.4%) were grade C, D or E according to intraoperative fluoroscopy images (Table 2). In the study, a total of 519 pedicle screws were placed. Of these, 483 (93.1%) were grade A or B and 36 (6.9%) were grade C, D or E according to postoperative CT images. Postoperative CT images allowed more sensitive and specific evaluation of pedicle screws than intraoperative fluoroscopy images. There was a significant difference in the grading of pedicle screws between postoperative CT images and intraoperative fluoroscopy images ($p<0.001$) (Table 2).

The quality, clarity, and angle of intraoperative fluoroscopy images were measured by the percentage of the surgical team finding the images adequate. 93.8% of the surgical team rated the quality of intraoperative fluoroscopy images as good or very good, and 6.2% as fair or poor. 96.2% of the surgical team rated the clarity of intraoperative fluoroscopy images as good or very good, 3.8% as fair or poor. 94.6% of the surgical team rated the angle of the intraoperative fluoroscopy images as good or very good, 5.4% as fair or poor (Table 3).

Table 2: Grading of pedicle screws according to intraoperative fluoroscopy images and postoperative computed tomography

Pedicle screw grade according to Gertzbein and Robbins classification in intraoperative fluoroscopy	**n (%)**	Pedicle screw grade according to Gertzbein and Robbins classification in computed tomography	**n (%)**	*p*-value
A	413 (79.6)	A	402 (77.5)	<0.001
B	83 (16.0)	B	81 (15.6)	<0.001
C	14 (2.7)	C	18 (3.5)	<0.001
D	6 (1.2)	D	12 (2.3)	<0.001
E	3 (0.6)	E	6 (1.2)	<0.001

Table 3: Evaluation of pedicle screws according to intraoperative fluoroscopy images

Intraoperative fluoroscopy image evaluation	Very good n(%)	Good n(%)	Fair n(%)	Poor n(%)
Quality	48 (50.5)	41 (43.2)	4 (4.2)	2 (2.1)
Clarity	51 (53.7)	40 (42.6)	3 (3.2)	1 (1.1)
Angle	49 (51.6)	40 (42.1)	4 (4.2)	2 (2.1)

Table 4: Evaluation of pedicle screws according to postoperative computed tomography

Postoperative computed tomography image evaluation	**n (%)**
Good congruence Incongruence	508 (97.9%) 9 (1.7%)
Loosening	2 (0.4%)
Stability Instability	510 (98.3%) 9 (1.7%)
No fatigue Fatigue fracture	516 (99.4%) 3 (0.6%)
No relationship with adjacent structures	491 (94.6%)
In relationship with adjacent structures	28 (5.4%)
Spinal canal Nerve roots Vessels Soft tissues	18 (64.3%) 6 (21.4%) 3 (10.7%) 1 (3.6%)
Malposition regions	
T11-L2 T6-T10 L3-S1	24.61% 14.07% 10.20%

The agreement between postoperative CT images and intraoperative fluoroscopy images had a sensitivity of 93.8%, specificity of 95.6%, positive predictive value of 98.8% and negative predictive value of 83.3%.

Postoperative CT images also showed the fit, stability and fatigue behavior of the pedicle screws to the vertebrae. A good congruence with the vertebra was observed in 97.9% (508/519) of pedicle screws, incongruence in 1.7% (9/519), and loosening in 0.4% (2/519). Stability was observed in 98.3% (510/519) and instability in 1.7% (9/519) of pedicle screws. There were no signs of fatigue in 99.4% (516/519) of the pedicle screws and 0.6% (3/519) of the pedicle screws had fatigue fractures (dislocated anterior to the vertebral corpus) (Table 4).

Postoperative CT images also showed the relationship of pedicle screws with adjacent structures. In 94.6% (491/519) of the pedicle screws, there was no relationship with adjacent structures, and in 5.4% (28/519) there was a relationship with adjacent structures. In 64.3% (18/28) spinal canal, 21.4% (6/28) nerve roots, 10.7% (3/28) vessels, and 3.6% (1/28) soft tissues were affected. Clinical symptoms or signs occurred in 57.1% (16/28) of pedicle screws associated with adjacent structures. Revision surgery was required in 35.7% (10/28) of pedicle screws associated with adjacent structures. When the frequency of the levels of screw malpositions with postoperative CT images was analyzed, the highest rate was found in T11-L2 (24.61%). The next most common levels were T6-T10 (14.07%) and L3-S1 (10.20%) (Table 4).

Discussion

The findings of this study suggest that there are significant differences between the use of intraoperative fluoroscopy and postoperative CT for the placement and evaluation of pedicle screws in spinal surgery. These findings are consistent with the available information in the literature. In particular, intraoperative fluoroscopy is widely used because of its immediate visualization during placement of pedicle screws, but postoperative CT is considered the gold standard that should be used for a more detailed analysis of pedicle screws (12,13).

The results of this study demonstrate that the positioning of pedicle screws can be immediately assessed by intraoperative fluoroscopy. With this technique, some possible complications during the placement of pedicle screws (such as screw malpositions) can be detected and corrected immediately. However, the results of this study showed that the ability of intraoperative fluoroscopy to precisely detect the position, depth and orientation of pedicle screws is limited. Furthermore, the images obtained by intraoperative fluoroscopy are generally low resolution and not sufficient to visualize complex vertebral anatomy in detail (14).

At this point, the importance of postoperative CT images becomes apparent. The results show that postoperative CT provides a more accurate and comprehensive method for the positioning and evaluation of pedicle screws. With this technique, screw malpositions, the depth and orientation of the screws, and their relationship with the vertebral structures could be detected much more precisely and clearly. Moreover, postoperative CT provided high efficacy and reliability in determining the integration, stability, and fatigue behavior of pedicle screws with the vertebrae and in detecting potential complications, risks, and side effects (15). These findings suggest that data obtained from postoperative CT may be important for the surgical team to determine whether reoperation is necessary (16).

In conclusion, both intraoperative fluoroscopy and postoperative CT are important imaging techniques for the placement and evaluation of pedicle screws in spinal surgery. However, each technique has its own advantages and limitations and should be chosen for the ideal application purpose and considering the circumstances that may arise.

The placement of pedicle screws in thoracolumbar spinal fusion surgery is a complex process that requires an understanding of spinal anatomy and biomechanics. In our study, we observed the highest rate of malposition in the T11-L2 segment, the reasons for this should be analyzed in detail. This region of the spinal column is located at the transition point between the thoracic and lumbar regions and therefore shows significant differences in anatomical and biomechanical properties. The vertebral morphology in this region can pose challenges for the placement of pedicle screws. In particular, the narrow size of the pedicle and the proximity of the spinal canal increase the sensitivity of screw positioning and increase the risk of malposition (17).

In addition to these anatomical features, biomechanical

stress in the T11-L2 region is also thought to affect the risk of malposition. The thoracolumbar transition zone is a point where the mobility and load-bearing capacity of the spinal column changes, which may affect the biomechanical forces applied to pedicle screws108. Furthermore, degenerative changes or pre-existing spinal pathologies in this region may further complicate the placement of screws and increase the malposition rate (18).

Our study emphasizes the importance of pedicle screw placement in spinal surgery and how this process is related to anatomical and biomechanical factors. These findings require surgeons to pay special attention to this region and take necessary precautions to reduce the risk of malposition. Furthermore, these results provide important information for the development of future surgical techniques and training programs.

In this study, demographic and clinical data of 94 patients who underwent thoracolumbar spinal fusion surgery were analyzed. Basic demographic information such as age, gender, height, weight and body mass index were analyzed and surgical indications were evaluated. Intraoperative fluoroscopy and postoperative CT images were critical during and after placement of pedicle screws.

Analysis of intraoperative fluoroscopy images was used to determine the placement and orientation of pedicle screws. Of the 519 pedicle screws obtained, the vast majority (approximately 95.6%) were grade A or B, while a small proportion were grade C, D or E. These findings demonstrate the precision and success of pedicle screw placement.

Postoperative CT images provided more detailed information about the position and orientation of the pedicle screws. With these images, important factors such as the fit of the screws to the vertebrae, stability, and fatigue behavior were examined. As a result of CT analysis, good alignment and stability were observed in the majority of pedicle screws (97.9%), but a small proportion showed mismatch and instability.

Impact on clinical practice and recommendations

The findings of this study provide a detailed account of the difficulties encountered during the placement of pedicle screws in thoracolumbar spinal fusion surgeries and the impact of this process on clinical practice. The results of the study provide important recommendations to improve practice in spinal surgery.

Increase Anatomical and Biomechanical Knowledge: The high malposition rates in the T11-L2 region emphasize the importance for spinal surgeons to deepen their anatomical and biomechanical knowledge in this area. This will enable surgeons to perform more precise and safe interventions in this complex region.

Use of Advanced Imaging Techniques: The effective use of intraoperative fluoroscopy and postoperative CT improves the accuracy and safety of pedicle screw placement. Widespread use of these techniques may improve surgical success rates and reduce the risk of complications.

Surgical Training and Simulation: In surgical training programs, it is recommended that special attention be paid to the thoracolumbar region and that skills in this area be developed through simulation and practical applications. This approach may increase the experience of surgeons and minimize the risks of malposition.

Patient Customized Planning: Recognizing that each patient's spinal anatomy is unique, surgical planning should be customized accordingly. Patient-centered approaches can contribute to improved surgical outcomes.

Integration of Technological Innovations: The use of innovative tools such as artificial intelligence and robotic technologies can provide greater precision and safety in the placement of pedicle screws. Integration of such technologies into surgical practice may improve surgical outcomes.

Multidisciplinary Approach: Closer collaboration between disciplines such as spinal surgery, neurology, radiology and physiotherapy could provide significant benefits in the comprehensive evaluation and treatment planning of patients.

Continued Clinical Research: More clinical research is needed in this area. In particular, it is important to obtain new findings to overcome the difficulties encountered in the placement of pedicle screws and to improve surgical techniques.

These recommendations are critical to increase the safety and efficacy of spinal surgery and improve patient outcomes. The results of this study may contribute to the development of approaches and techniques in the field of spinal surgery, which will directly affect clinical practice and patient care.

Conclusions

The results of this study provide important information for the evaluation of techniques and imaging modalities used in the placement of pedicle screws. Comparative analysis of intraoperative fluoroscopy and postoperative CT images provided critical data for improvements in spinal surgical practice. These findings will contribute to taking important steps towards increasing the success of pedicle screw placement and improving surgical safety.

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Informed consent: The authors have obtained the approval of the Ethics Committee for the analysis and publication of clinical data obtained routinely. The informed consent of the patients was not required because it was a retrospective observational study.

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Contributions

Research concept and design: HCC, BG

Data analysis and interpretation: HCC, BG

Collection and/or assembly of data: HCC, BG

Writing the article: HCC

Critical revision of the article: HCC, BG

Final approval of the article: HCC, BG

All authors read and approved the final version of the manuscript.

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