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Unilateral biportal endoscopic lumbar interbody fusion assisted by a Tianji robot for lumbar degenerative disease in elderly patients: a retrospective study

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Abstract

Background Unilateral biportal endoscopic lumbar interbody fusion (UBE-LIF) has been successfully used to treat degenerative lumbar spinal diseases. Nevertheless, the duration of the UBE-LIF procedure notably exceeds that of minimally invasive transforaminal lumbar interbody fusion (Mis-TLIF), increasing the potential for perioperative complications, particularly in elderly patients.

Objective This retrospective study aimed to compare the results of robot assistance (RA) and non-assistance (NA) groups and to explore the benefits of UBE-LIF assisted by a Tianji robot in aged patients.

Methods 60 patients were divided into two groups: 30 patients in the RA group and 30 in the NA group from January 2022 to June 2023. The surgical duration, estimated intraoperative blood loss, postoperative drainage, length of hospital stays, and radiation exposure were examined and documented. Clinical assessments, including the Oswestry Disability Index (ODI), visual analog scale (VAS), modified MacNab criteria, postoperative complications, and interbody fusion rate, were also evaluated.

Results No significant differences were observed between the two groups in terms of postoperative drainage, length of postoperative hospital stay, or fusion rate. However, the RA group exhibited lower perioperative complications, estimated intraoperative blood loss, and duration of radiation exposure than the NA group. The average total operation time in the RA group was 105.3 ± 25.8 min, which was significantly shorter than the NA group's average of 130.5 ± 22.5 min ($P < 0.001$). Furthermore, both groups demonstrated improvements in all clinical outcomes at various postoperative time points, with no significant differences between them ($P > 0.05$).

Conclusions Compared with the NA approach, robot-assisted UBE-LIF technology provides accurate intraoperative guidance and helps spinal surgeons achieve accurate decompression. Furthermore, it can reduce radiation exposure, operation time, blood loss, and surgical complications, thereby improving the surgical efficiency and safety.

Keywords Unilateral biportal endoscopic lumbar interbody fusion, Robot assistance, Postoperative complications, Mis-TLIF

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Introduction

Elderly individuals afflicted with lumbar disc degenerative disease (LDDD), which includes lumbar disc herniation, lumbar spinal stenosis, degenerative spondylolisthesis, and degenerative scoliosis, frequently encounter symptoms such as sciatica, lower limb pain, radiating discomfort, claudication, and lower back pain (LBP), significantly disrupting their daily activities. Minimally invasive spinal surgery (MISS) has gained popularity among surgeons and patients as an effective treatment for LDDD. It offers the advantages of reducing intraoperative trauma, bleeding, and postoperative pain and enables faster recovery. A specific technique called unilateral biportal endoscopic lumbar interbody fusion (UBE-LIF) was introduced by Heo et al. in 2017 and has shown promising clinical outcomes [1]. UBE-LIF involves utilizing two separate transmuscular channels as observation and operation portals, allowing for an improved surgical perspective and versatile manipulation of surgical instruments. This technique enables various MISS procedures including unilateral laminotomy, bilateral laminotomy, lumbar discectomy, and interbody fusion, resulting in favorable clinical efficacy [2–5].

Although UBE-LIF has been proven to offer advantages over MIS-TLIF in terms of reduced intraoperative blood loss, postoperative drainage, and shorter hospital stays, it is important to recognize that UBE-LIF generally requires longer operative times than Mis-TLIF. Research conducted by Liu G et al. [6] and Kang et al. [7] reported average operative times of 5.12 ± 1.76 h and 170.46 ± 34.81 min, respectively, for single-segment UBE-TLIF procedures. Prolonged surgical procedures have been linked to an increased risk of postoperative complications such as pneumonia, surgical site infections, and venous thromboembolism [8]. These complications can be detrimental to patients, particularly those who are elderly, and can have fatal consequences [8]. Therefore, it is crucial to prioritize the development and implementation of strategies aimed at minimizing the surgical duration, benefiting both patients and surgeons while ensuring safety.

The incorporation of digital medical technology has enabled the successful use of robots and navigation systems in lumbar interbody fusion procedures, resulting in good clinical outcomes [9]. Studies have highlighted the potential of these technologies to improve surgical efficiency and reduce radiation exposure for both surgeons and patients [9, 10]. However, to the best of our knowledge, the specific advantages of employing Tanji robots and O-arm navigation in assisting UBE-LIF have not been previously reported. The objective of our study was to introduce UBE-LIF aided by an intraoperative Tanji robot (developed by Beijing TINAVI Medical Technologies) and O-arm navigation and compare its effectiveness to that of traditional fluoroscopy-assisted UBE-LIF.

Materials and methods

Study design and patient population

We conducted a retrospective analysis of 60 elderly patients with UBE-LIF who underwent treatment with robotic assistance (n = 30) and traditional C-arm fluoroscopy assistance (n = 30) at our spine center between January 2022 and June 2023.

Inclusion and exclusion criteria

The inclusion criteria were as follows: (1) aged between 60 and 90 years; (2) definite diagnosis of lumbar stenosis, lumbar spondylolisthesis, or lumbar instability; and (3) no response to appropriate conservative treatment for three months.

The exclusion criteria were as follows: (1) unsuitable for anesthesia owing to poor physical or mental health; (2) high-grade (> grade 2) spondylolisthesis, active infection, or spinal tumor; and (3) less than 12 months of follow-up or incomplete clinical data.

The two groups underwent a comparative analysis based on data collected during the perioperative period, including estimated blood loss, length of hospital stay, and radiation exposure. The radiologist evaluated spinal interbody fusion by examining the CT images obtained at least 12 months postoperatively. Surgical outcomes were assessed using the Visual Analog Scale (VAS) score, Oswestry Disability Index (ODI), and perioperative surgical complications.

UBE-LIF was assisted by the Tanji robot surgical procedure (RA group)

Under general anesthesia, the patient was placed in a prone position on a radiolucent table. To provide stability, two Kirschner wires (K-wires) were used to anchor the reference frame to the posterosuperior iliac crest. The surgical section was scanned using an O-arm (Fig. 1A), and the resulting images were then transferred to a workstation, allowing the surgeon to simulate the positioning of the pedicle screws (Fig. 1B). Once the pedicle screw positions were planned, the robotic arm automatically adjusted its position, enabling the surgeon to accurately drive the four K-wires into the vertebrae (Fig. 1C). In addition, the Tanji robot utilized a navigation system that facilitated real-time tracking and intraoperative identification of the anatomical structure (Fig. 1D).

Guided by the Tanji robot, two skin incisions were made during the procedure. Two skin incisions were made approximately 0.5 cm lateral to the corresponding spinous process. Serial dilators were applied to gradually enlarge the two channels (the working and endoscopic

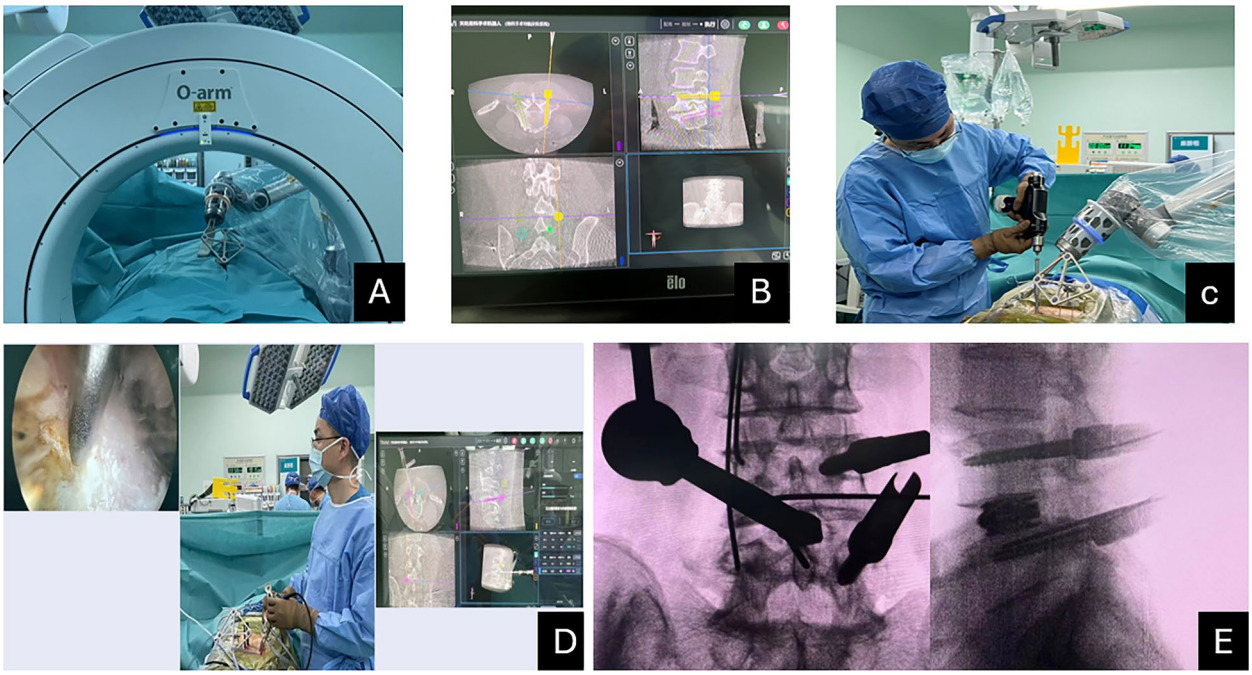

Fig. 1 Surgical procedure of UBE-LIF assisted by the Tanji Robot. **A** Surgical site imaging was scanned by the O-arm and then sent to a workstation. **B** The surgeon virtually mapped the trajectory for pedicle screws on a workstation. **C** Assisted by the Robotic arm, the surgeon inserted four K-wires into the vertebrae. **D** Tanji robot's navigation system assisted in identifying lumbar structures during the procedure. **E** A cage was inserted under endoscopic monitoring and pedicle screws were percutaneously implanted with guidance from the four K-wires

channels). An initial submuscular working area was established on the surface of the lamina, guided by endoscopic instructions. A saline irrigation system was used for the natural drainage. A special stripper tool was used to remove the paraspinal muscle from the articular and spinous processes of the lamina, while a 90-degree radiofrequency probe (BONSS®, Taizhou, China) was employed to stop bleeding and reveal the surgical space.

The inferior articular tissue was excised using a chisel (Fig. 2A). Employing a rongeur, the medial part of the

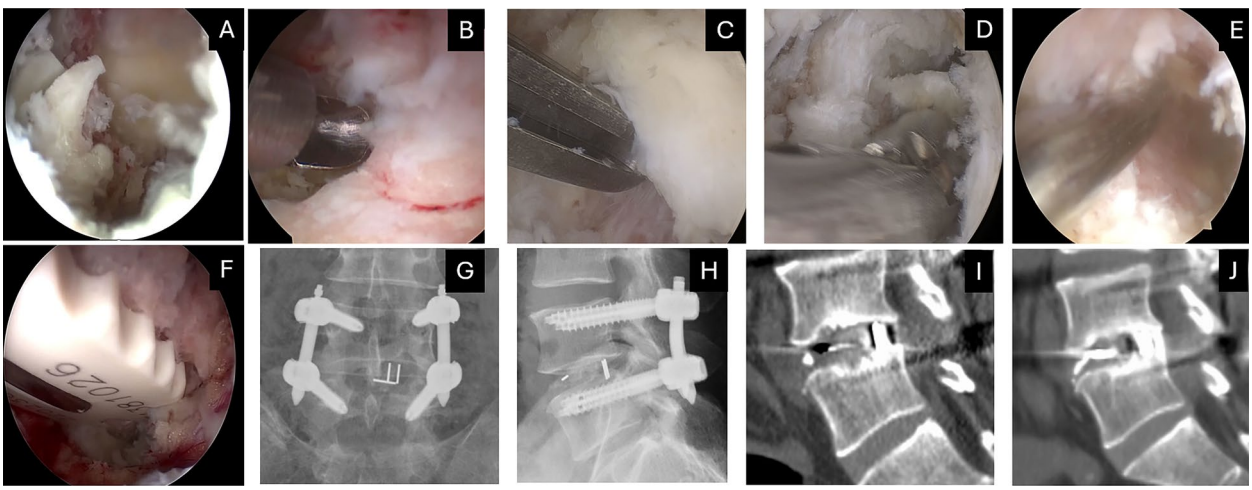

Fig. 2 Surgical procedure of BE-LIF and interbody fusion follow up. **A** The inferior articular is chiseled out. **B** The media portion of the superior articular is removed using a rongeur. **C** The flavum ligament is rongeured. **D** The nucleus pulposus tissue is excised. **E** The cartilage endplate is scraped off. **F** The cage is inserted. **G, H** The anteroposterior and lateral view after surgery is displayed. **I** Interbody fusion is shown 6 months after surgery. **J** Interbody fusion is shown 12 months after surgery

articular process, lower border of the upper lamina, and upper border of the lower lamina were removed (Fig. 2B). All retrieved bone fragments were reserved for interbody fusion. Subsequently, the ligamentum flavum was excised to expose the spinal canal (Fig. 2C), and the nerve roots were safeguarded using a nerve retractor. The intervertebral discs and endplate cartilage were eliminated by direct visualization (Fig. 2D, E). Following complete removal of cartilage, bone fragments were inserted and compacted in front of the targeted disc region. A cage of an appropriate size was then inserted (Fig. 2F). After cage insertion, four pedicle screws were percutaneously implanted and guided by four K-wires (Fig. 1E). The placement of the pedicle screws and cage was verified using C-arm fluoroscopy (Fig. 2G, H), and the surgical wound was closed upon removal of the instruments and endoscope.

Surgical technique for UBE-LIF without robotic assistance (NA)

The routine UBE-LIF procedure was performed as previously described (1).

Outcomes and measurements

Demographic data, including age, sex, body mass index, bone density, and operative time, were collected. Intraoperative blood loss, postoperative drainage, duration of hospital stay, and duration of radiation exposure were recorded. Clinical outcomes such as the Oswestry Disability Index (ODI), visual analog scale (VAS), modified MacNab criteria, and postoperative complications were assessed. Pedicle screw placement accuracy assessment was based on the Gertzbin–Robbins classification (Group A, screw position within the pedicle; Group B, cortical breach of less than 2 mm; Group C, cortical breach of 2 mm or more but less than 4 mm; Group D, cortical breach of 4 mm or more but less than 6 mm; and Group E, cortical breach of 6 mm or more).After one year, computed tomography (CT) was performed to evaluate the fusion rate using the Bridwell interbody fusion grading system, which was graded by two blinded observers who were unaware of the patients' identities (Fig. 2I, J). The Bridwell interbody fusion grading system is categorized as follows:

Grade I: Complete fusion, with continuous trabeculae passing through the intervertebral graft area, no lucency, and no obvious gap between the fusion cage and the vertebral body.
Grade II: Questionable fusion, with partial trabeculae formation in the graft area, but still some lucency exists, and there may be a slight gap between the fusion cage and the vertebral body.
Grade III: Non-fusion, with no obvious trabeculae formation in the graft area, obvious lucency, and a clear gap between the fusion cage and the vertebral body, and even cage displacement may occur.
Grade IV: Pseudarthrosis, not only no fusion, but also abnormal movement and bone resorption occur.

Statistical analysis

IBM SPSS Statistics software (version 26.0; IBM Corp., Armonk, NY, USA) was used for statistical analysis. The results are expressed as the mean ± standard deviation or frequency. Repeated-measures analysis of variance was used to analyze the clinical outcomes (VAS score and ODI for back and leg pain) between the two groups and changes over time in each group. The independent sample t-test, chi-square test, and Mann–Whitney U test were used to examine differences between the two groups, as appropriate, based on different categories of data. The level of statistical significance was set at $P < 0.05$.

Results

No significant differences were observed in demographic data between the RA and NA groups (Table 1).

The radiation exposure in the RA group was significantly lower than that in the NA group in every segment, with a dose of 36.99 ± 12.2 mGy compared to 52.3 ± 12.2 mGy ($P < 0.01$). The exposure time was also shorter in the RA group at 6.9 ± 2.3 s compared to the NA group's 30.5 ± 5.0 s ($P < 0.01$). The estimated intraoperative blood loss was 80.0 ± 8.5 ml in the RA group and 125.5 ± 15.0 ml in the NA group ($P < 0.01$), and postoperative drainage was 56.0 ± 10.5 ml in the RA group and 65.5 ± 15.5 ml in the NA group ($P < 0.01$). The RA group also had shorter postoperative hospital stays at

Table 1 Comparison of demographic data between the two groups

	RA Group (n = 30)	NA Group (n = 30)	P-value
Age (years)	64.3 ± 3.3	65.8 ± 5.7	0. 45
Gender (Male: Female)	18:12	16:14	0.27
BMI (m/Kg^2)	26.5 ± 1.7	25.5 ± 1.3	0.53
BMD (T-score)	− 1.8 ± 1.3	− 2.1 ± 1.5	0.22
Operation level (%)			
L3/4	3 (10.0%)	2 (6.0%)	0.61
L4/5	18 (60.0%)	15 (53.3%)	
L5S1	7 (26.7%)	11 (36.6%)	
L3/4, L4/5	1 (1.7%)	1 (1.7%)	
L4/5, L5S1	1 (1.7%)	1 (1.7%)	

6.3 ± 3.2 days compared to the NA group's 5.8 ± 4.5 days (P < 0.01). The average total operation time was 105.3 ± 25.8 min in the RA group with single segment interbody fusion, which was shorter than that in the NA group's 130.5 ± 22.5 min (P < 0.001). The average total operation time was180.6 ± 35.8 min in the RA group with 2-segments interbody fusion, which was shorter than that in the NA group's 205.6 ± 29.8 min.

Both groups showed significant improvement in VAS score and ODI at different time points after surgery (Table 2), without any notable differences between the two groups. The excellent and good rates in the MacNab criteria assessment were comparable between the RA (93.3%) and NA (86.7%) groups, with no significant differences. Each group had one case of dural tear, which was successfully treated conservatively. In the NA group, one case of nerve root injury required revision surgery due to poor pedicle screw position. Additionally, one case of surgical site infection was observed in the NA group, which was resolved with a 6-week course of antibiotic treatment. Both groups underwent single-cage withdrawal and reoperation. After 12 months, the spinal fusion rates were 90.0% (27 patients) in the RA group and 86.7% (26 patients) in the NA group, showing no significant difference between the two groups.

Assessment of pedicle screw accuracy was based on the Gertzbin-Robbins classification. In the RA patient group, 118 (95.2%) out of 124 pedicle screws were categorized as group A, while 6 (4.8%) were in group B, with none falling into groups C-E. Conversely, in the NA group, only 109 (88.0%) of 124 pedicle screws were in group A, 5 (4.0%) were in group B, 5 (4.0%) were in group C, and 5 (4.0%) were in group D, E. This discrepancy was statistically significant (P = 0.004). Misplacement of the pedicle screw in group E led to nerve root injury, resulting in quadriceps weakness,

Although the patient fully recovered six months after undergoing revision surgery, the cost was too high.

Table 2 Comparison of clinical outcome between the two groups

	RA Group (n = 30)	NA Group (n = 30)	P value
VAS of low back			
Preoperative	6.2 ± 2.5	6.7 ± 4.5	0.628
Postoperative			
3 Days	2.5 ± 1.0	2.4 ± 1.3	0.293
3 Months	2.7 ± 1.2	2.3 ± 1.3	0.242
12 Months	2.4 ± 1.5	2.5 ± 1.3	0.625
VAS of leg pain			
Preoperative	7.3 ± 2.0	7.7 ± 3.5	0.253
Postoperative			
3 Days	2.3 ± 1.2	2.4 ± 1.3	0.385
3 Months	1.8 ± 0.8	1.9 ± 1.2	0.529
12 Months	1.7 ± 1.2	2.0 ± 1.5	0.258
ODI scores			
Preoperative	56.8 ± 9.0	60.8 ± 12.4	0.605
Postoperative			
3 Months	12.3 ± 2.5	11.2 ± 1.7	0.328
12 Months	8.6 ± 2.7	8.9 ± 1.9	0.426
MacNab criteria (n)			
Excellent	18	15	0.229
Good	10	8	
Fair	2	6	
Poor	0	1	
Screws assessment			
A	118	109	0.034
B	6	5	
C	0	5	
D	0	4	
E	0	1	
Fusion at 12 months			
Grade I	25	23	0.808
Grade II	2	3	
Grade III	3	4	
Grade IV	0	0	
Complications			
Nerve root injury	0	1	0.741
Dural tears	1	1	
Infection	0	1	
Cage retreatment	1	1	

Discussion

UBE-LIF is a minimally invasive surgical technique that offers several advantages over traditional open lumbar fusion and mis-TLIF surgeries. It is associated with less trauma, less postoperative pain, and a faster recovery time, while achieving similar or better clinical outcomes and fusion rates [11, 12]. The UBE-LIF process is a lengthy and complex procedure influenced by several factors that may lead to increased perioperative complications. One of the main issues is that the instrument tends to dislodge because of the intricate spinal structure. Moreover, the technique does not provide direct visualization of the surrounding anatomical structures, making it challenging to determine the current location and causing confusion among surgeons. Finally, pedicle screw implantation requires a considerable amount of time.

The duration of the surgical procedure has been found to have a significant impact on perioperative complications, as indicated by Saleh's research [8]. According to the study, patients with operative times less than 120 min had a lower likelihood of experiencing complications than those with operative times ranging from 120

to 180 min (OR: 1.77 [95% CI 1.27–2.47]). Furthermore, patients whose procedures exceeded 180 min were at an elevated risk of complications (OR: 3.07 [95% CI 2.23–4.22]). Hence, it is crucial to optimize and minimize the operative time to decrease the incidence of complications and expand the applicability of the UBE-LIF technique. The average total operation time for the RA group was 105.3 ± 25.8 min, characterized by a lower likelihood of encountering complications. In contrast, the NA group had an average total operation time of 130.5 ± 22.5 min, accompanied by a higher likelihood of complications.

The use of robot-assisted technology has made spinal surgery less complicated and reduced the operative time [10]. The Tanji robotic system offers several benefits in spinal surgery. First, it streamlines the planning of screw pathways, selection of screw size, and transfer of K-wires and screws into the vertebrae, allowing for a more efficient and safe procedure. In addition, the robot was equipped with a navigation system that enabled real-time tracking and identification of the anatomical structures of the spine, thereby reducing the risk of confusion and saving time. Most significantly, robot-assisted UBE-LIF technology enhances the accuracy of pedicle screw implantation and minimizes complications of nerve root injury.

In this study, the robot-assisted UBE-LIF group experienced significantly lower estimated intraoperative blood loss, and shorter radiation exposure duration than the NA group, owing to the reduced operative time. Clinical evaluation measures such as VAS score, ODI, Modified MacNab criteria, and fusion rate did not significantly differ between the two groups. These findings suggest that Tanji robot-assisted UBE-LIF not only produces clinical outcomes similar to those of traditional UBE-LIF, but also offers advantages such as accurate intraoperative decompression, percutaneous pedicle screw placement, and reduced radiation exposure, which enhance surgical efficiency. Although there was no statistically significant difference in surgical complications between the two groups, the RA group showed a superiority in reducing screw-related complications compared to the NA group. In the present study, mispositioning of the pedicle screw in the NA group resulted in nerve root injury, leading to quadriceps weakness. Although the patient fully recovered six months after undergoing revision surgery, the cost was too high.

Limitation

This was a single-center retrospective study with a small sample size and relatively short follow-up period. Furthermore, the data collection was prone to retrospective bias. Additional randomized controlled trials with larger sample sizes are required to confirm the effectiveness and safety of robot-assisted UBE-LIF.

Conclusions

In summary, robot-assisted UBE-LIF technology offers several advantages over traditional UBE-LIF techniques. It enables precise intraoperative guidance and enables spinal surgeons to accomplish accurate decompression and interbody fusion procedures. Additionally, this innovative technology helps to minimize radiation exposure, shorten operation time, decrease blood loss, lower the risk of neurological injuries, and reduce screw-related complications, ultimately improving the efficiency and safety of surgical procedures. The successful implementation of a UBE-LIF robot assistant in the treatment of LDDD has demonstrated its effectiveness and safety, establishing it as a promising option for broader applications in this field.

Author contributions

Conception and design: Fang Guofang and Sang Hongxun. Acquisition of data: Zhang Jin, Lai Xunwei and Zhu Hailuan. Analysis and interpretation of data: Fang Guofang and Li Xiuwang. Drafting the article: Fang Guofang, Wu Jiachang and Chen Fangxin. Critically revising the article: Sang Honxun.

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Availability of data and materials

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

This study was approved by the Ethics Committee of *** Hospital, and informed consent was obtained from all patients.

Consent for publication

All physicians consented to the use of images showing their faces and all the authors have approved the manuscript and that is enclosed.

Competing interests

The authors declare no competing interests.

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