



An anatomical study of the origins courses and distributions of the transverse branches of lumbar arteries at the L1–L4 levels

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Received: 24 June 2021 / Revised: 5 December 2021 / Accepted: 13 January 2022 / Published online: 30 January 2022
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Abstract

Summary of background Pseudoaneurysms of the lumbar arteries following transforaminal lumbar interbody fusion (TLIF) are rare postoperative complications that usually occur around the transverse process. However, there are few detailed descriptions of the transverse branch and other branches of the dorsal branches at the L1–L4 disks.

Study design Ten adult embalmed cadavers were anatomically studied.

Objectives The purposes of the study were to describe the vascular distribution of the dorsal branches, especially the transverse branches, at the L1–L4 levels and provide information useful for TLIF.

Methods Ten embalmed cadavers studied after their arterial systems were injected with red latex. The quantity, origin, pathway, distribution range and diameter of the branches were recorded and photographed.

Results The transverse branch appeared in all 80 intervertebral foramina. The transverse branch was divided into 2 types: In type 1, the arteries divided into superior branches and inferior branches; the arteries in type 2 divided into 3 branches (superior, intermedius and inferior branches).

Conclusions The transverse branches of the dorsal arteries are common structures from L1 to L4, and 2 types of transverse branches were found. A thorough understanding of the dorsal branches, especially the transverse branches of the lumbar artery, may be very important for reducing both intraoperative bleeding during the surgery and the occurrence of pseudoaneurysms after transforaminal lumbar interbody fusion.

Keywords Clinical anatomy · Pseudoaneurysm · Lumbar vertebra · Lumbar artery · TLIF

The first three authors contributed equally to this work and should be considered as co-first authors.

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Introduction

Although transforaminal lumbar interbody fusion (TLIF) is an efficacious and common surgery for degenerative lumbar diseases, many researchers have reported that the rate of postoperative complications related to TLIF is as high as 36% [1–3]. These complications include vascular injury, neurological injury, infection, and the extremely rare complication of pseudoaneurysm (PSA) [1–3]. Keerthivasan and Maurizio reported a PSA after TLIF but indicated that the mechanism was unclear [4, 5]. In most cases, the PSA occurred around the transverse process and facet joint, according to imaging findings, which suggests that a detailed anatomic understanding of the ramifications of the dorsal branch (Db) around that area is necessary to reduce the rate of such postoperative complications.

Originally, Nojiri et al. [6] reported an anatomic description of the lumbar arteries (LAs) and intervertebral disk.

As for the detailed branches of the LAs, Zhao et al. [7] reported further information on the anatomy of these vessels in the intervertebral zone, especially the distribution of the postcentral branches. Mehmet and Caglar illustrated and described the LAs and their branches in the extraforaminal zone, and they divided the Dbs into four branches: the ganglionic, transverse, ascending and descending branches [8–10]. Furthermore, Tatara et al. [11] identified the anatomical relation between the LAs and the spinal nerves. However, these researchers did not describe the Db or its branches precisely, especially not in the area around the transverse process and facet joint.

In this study, the origins, courses and distributions of the Db from L1 to L4, including the transverse branches (Tbs), were studied. We investigated the details of the Db and the possible clinical significance of these branches in reducing the incidence of PSAs.

Materials and methods

A total of 80 LAs at the L1–L4 levels from 10 embalmed human cadavers (7 male and 3 female cadavers; mean age, 65.8 years) were analyzed. There was no evidence of a previous spinal surgery or spinal pathology in these cadavers. All cadavers were injected with 10% formalin in the femoral artery with a syringe and soaked in a formalin pool for 2–3 years. The arterial systems were injected with red latex in the femoral artery. After cooling for 24 h, the cadavers were immersed in the formalin pool again, and the test began 1 week later.

The lumbar segments were identified by the spinous processes on the cadaver, and specimens of the lumbar segments were cut with an electric saw. The subcutaneous tissues and fascia were dissected on the dorsal side of cadavers. The multifidus muscle and the longissimus were separated by blunt dissection, and the arteries were examined. On the ventral side, the abdominal organs, the psoas major and quadratus were carefully removed. Next, the loose connective tissue and adjacent adipose tissue were carefully removed by standard microsurgical techniques (Carl Zeiss, Jena, Germany). The Db branches that run along the surface of the intervertebral disk were carefully dissected and identified.

At each level, the quantity, origin, pathway, distribution range, diameter of the Db branches were recorded, and distance from the point where the Tb emerged from the surface of the multifidus to the middle point of the base of the transverse process, the lateral point of the superior articular process and the supraspinous ligament were recorded and photographed. The diameter of the artery was measured with a Vernier caliper (accurate to 0.01 mm) under an operating microscope.

We used the standard, widely available SPSS software to analyze the recorded measurements. The relevant data were expressed as “ $\bar{X} \pm SD$.” “ \bar{X} ” represents the average diameter of the artery, and “SD” represents the standard deviation of these arterial diameters. Continuous data were analyzed by one-way ANOVA. (The diameters of different transverse branches were compared at the L1–L4 levels.) The threshold for statistically significant was set to $p < 0.05$.

Results

In our study, the Tb appeared in all 80 intervertebral foramina. Tbs were classified into two types (Fig. 1): In type 1, the Tb divided into superior branches and inferior trunks; in type 2, the Tb divided into 3 branches (superior, intermedium and inferior branches).

Twenty-nine (36.25%) Tbs of type 1 were demonstrated. The main trunks originated from the Db penetrated the multifidus muscle and divided into two branches at the base of the transverse process. The superior branches were close to the base of the transverse process, moved toward the superior articular process, and anastomosed with the descending inferior branch from the superior segment to form the adjacent organization. The inferior branches traveled to the inferior articular process and formed the adjacent organization with the Tbs from the inferior vertebral body.

A total of fifty-one (63.75%) Tbs of type 2 were found in the specimens. The superior branches were found to be concentrated in the area of the transverse process. The movement of these branches was the same as that of the type 1 branches. The intermedium branches moved toward the multifidus muscle and nourished adjacent muscles and surrounding tissues. The movement of the inferior branches did not differ between types 1 and 2.

Twenty-four (30.00%) Tbs that moved through the multifidus were found (Fig. 2). There were twenty-two (91.67%) type 2 branches and two (8.33%) type 1 branches. Sixteen (66.67%) arteries were found in the L2–L3 segment, which was the most common site, and the exposed arteries were longer than those in the other segments. In the other segments, there were two (8.33%) arteries at the L1–L2 level, two (8.33%) arteries at the L4–L5 level and four (16.67%) arteries at the L3–L4 level. The distance from the point where the Tb emerged from the surface of the multifidus to the middle point of the base of the transverse process was 4.97 ± 0.92 mm (range, 2.62–5.87). The distance from the same point to the lateral point of the superior articular process was 4.47 ± 1.20 mm (range, 2.10–7.06). The horizontal distance from the same point to the supraspinous ligament at the same level was 21.20 ± 3.00 mm (range, 15.40–25.10).



Fig. 1 Dorsal view of the transverse branch arteries in the right side. Photographs (a) describe the Tb in type 1, and photographs (b) describe the Tb in type 2. Cr, cranial; D, disk; La, lumbar artery; Lb, lateral branch; Db, dorsal branch; Tb, transverse branch; 1, superior

branch; 2, intermedium branch; 3, inferior branch; Deb, descending branch; Snb, spinal nerve branch; Sa, spinal artery; n, nerve root; Tp, transverse process; Sp, superior articular process; Mm, multifidus muscle

There were no significant differences in the measurements across segments ($P > 0.05$). Table 1 shows the measured values of the Db and Tbs for each segment.

Discussion

Caglar et al. [9] reported that the Db divides into 4 branches, but their study was limited to the levels above the quadratus lumborum muscle. Nojiri et al. [6] reported that the branches of the LA were more common in the L4–L5 segment than in the other segments, and they observed that surgery on the L4–L5 segment was accompanied by more bleeding than surgery on other segments. In our study, we found that the Db divides into four

branches, as described by Caglar. The Tb was the thickest branch and was located close to the superior articular process and the base of the transverse process. Most of these branches were classified as type 2, as there were 3 branches moving toward the multifidus (Fig. 3).

Yasunori et al. [11] studied the origin and distributions of the ganglionic branches. These authors described the radicular branch, the spinal nerve branch and the plexus branch. Zhao et al. [7] identified two types of postcentral branches, and the branches were distributed from the anterolateral region of the disk to the posterior region. We found the Tb at all levels, and the Tb connected to the multifidus most frequently at L2 and occasionally appeared in other segments. We also found that the diameter of the Tbs did not differ across segments.

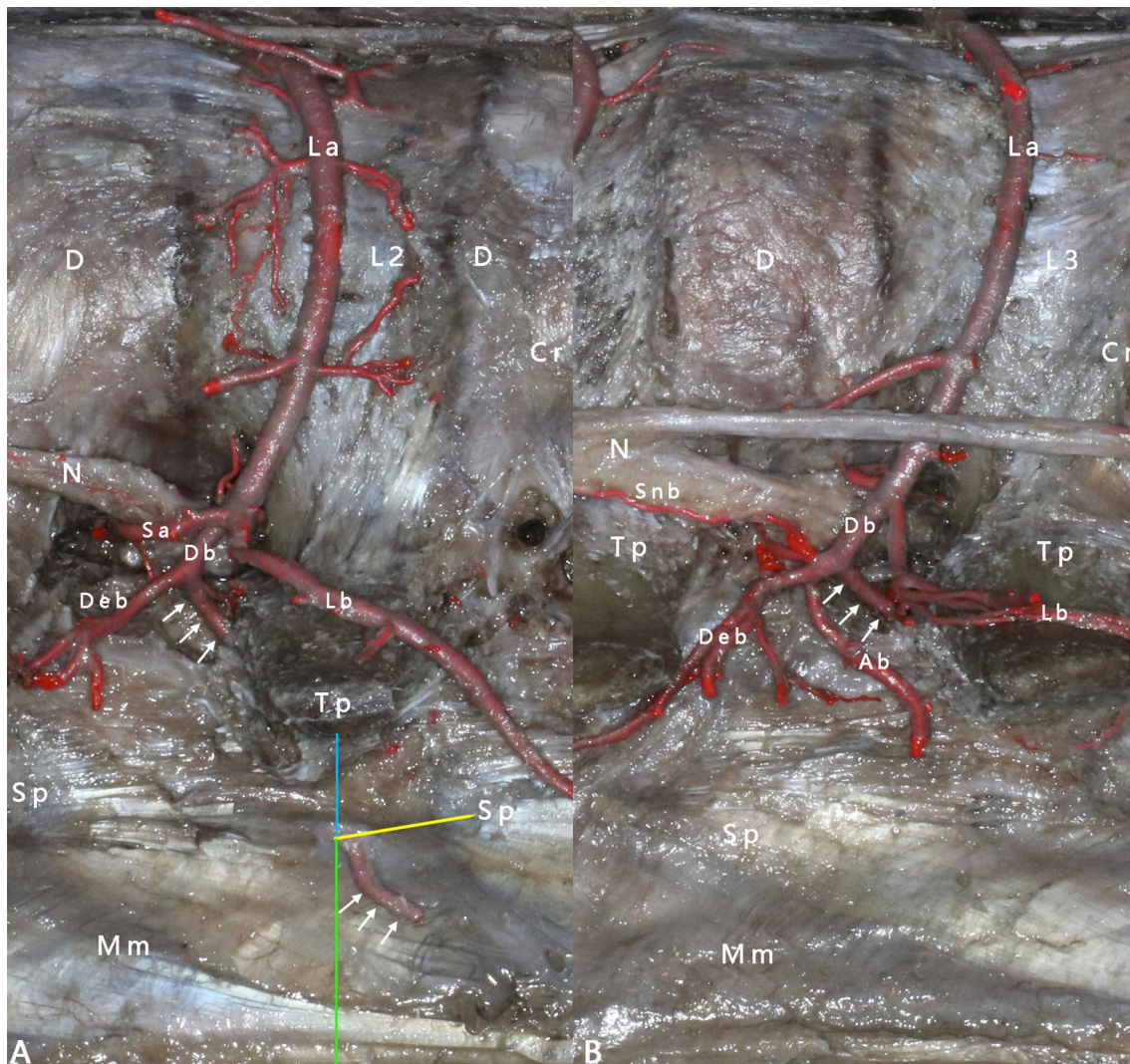


Fig. 2 Dorsal view of the transverse branch arteries in the left side; photographs (a) describe the Tb with the perforating point, and photograph (b) describes the Tb without the perforating point. Cr, cranial; D, disk; La, lumbar artery; Lb, lateral branch; Db, dorsal branch; Tb, (white arrow) transverse branch; Deb, descending branch; Ab, ascending branch; Snb, spinal nerve branch; Sa, spinal artery; n, nerve root; Tp, transverse process; Sp, superior articular process;

Mm, multifidus muscle. The blue line indicates the distance from the perforating point to the middle point of the base of transverse process; the yellow line indicates the distance from the perforating point to the lateral point of superior articular process; and the green line indicates the horizontal distance from the perforating point to the supraspinous ligament

Transverse process fracture (TPF) is a symptom that occasionally occurs in spinal diseases [12, 13]. Many scholars have reported that TPFs are relatively minor or minimally painful injuries; in those studies, no patients with TPFs were hospitalized, and all patients were treated conservatively without severe complications [14–19]. However, Liu et al. [20] found that TPF was related to lumbar artery injury in a retrospective study. Maurizio et al. [5] reported that PSAs are associated with vertebral fractures, especially TPFs. Young et al. [21] reported LA injury caused by basal fracture of the transverse process during transforaminal endoscopic discectomy in one case, causing PSAs. We suspect

that TPF may occur in TLIF because of osteoporosis in the elderly. We believe that the superior postoperative effect of TLIF might depend on the surgeon's understanding of the Tb. The occurrence rate of the Tb is 100%, and the proportion of a Tb without perforation points is 70%. If the surgeon separates the erector spinal muscle too far or operates in the region of the transverse process, the Tb may be damaged, resulting in massive bleeding and accumulation of blood in the muscle, causing PSAs. Therefore, when the TLIF surgical site involves the vicinity of the transverse process or encounters the TPF, it is necessary to assess whether the Tb has been injured. Instead of conservative treatment at the

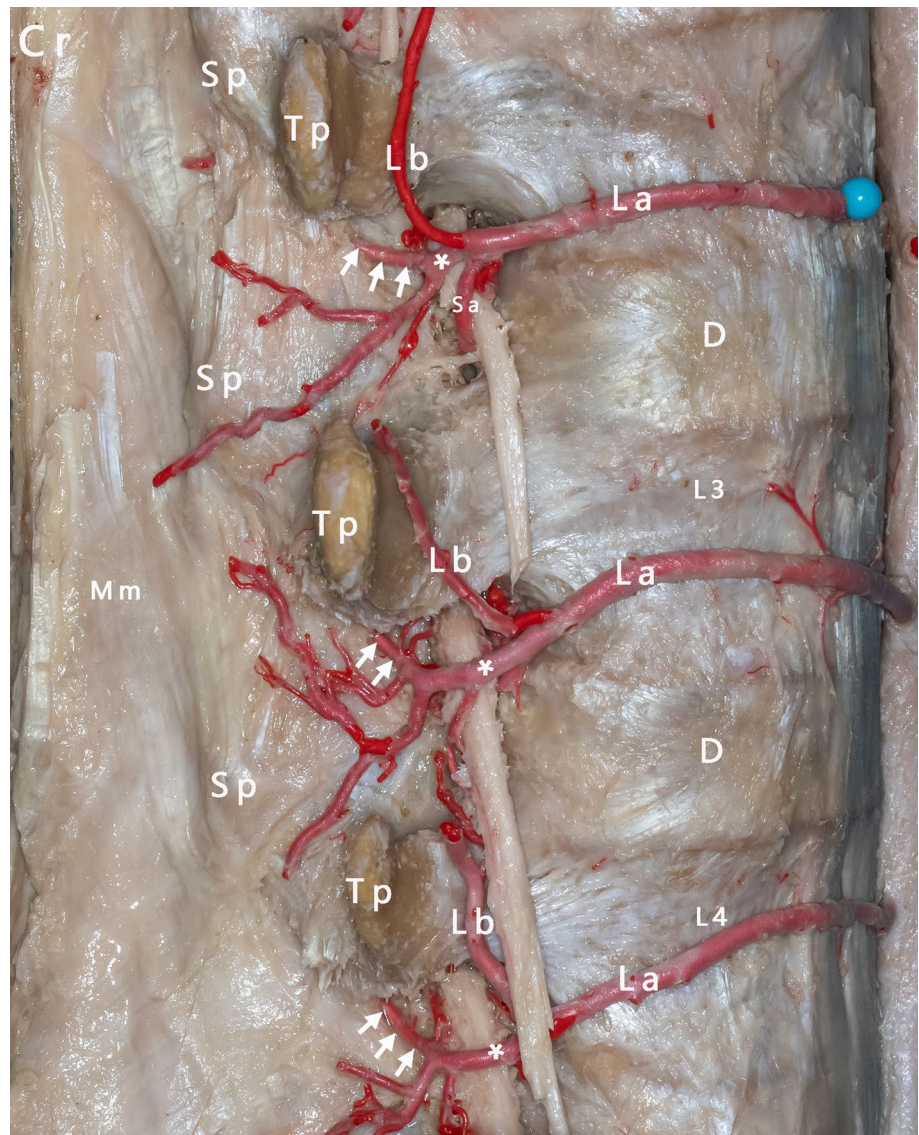
Table 1 The measurements of the transverse branches

Vertebral segments	Type	Number	Dia.1	Dia.2	Dia.3	Dia.4	Dia.5
L1–L2	Type 1	15	0.74±0.08	0.30±0.03	–	–	–
	Type 2	5	–	–	0.65±0.18	0.37±0.05	0.28±0.05
L2–L3	Type 1	3	0.74±0.06	0.32±0.04	–	–	–
	Type 2	17	–	–	0.73±0.10	0.30±0.08	0.20±0.06
L3–L4	Type 1	6	0.75±0.57	0.31±0.22	–	–	–
	Type 2	14	–	–	0.76±0.79	0.31±0.08	0.23±0.75
L4–L5	Type 1	5	0.77±0.66	0.36±0.11	–	–	–
	Type 2	15	–	–	0.76±0.47	0.30±0.47	0.22±0.06
1-way analysis of variance			$F=0.221$ $P=0.881$	$F=1.397$ $P=0.267$	$F=1.845$ $P=0.152$	$F=1.319$ $P=0.219$	$F=1.923$ $P=0.139$

Values are represented as $\bar{X} \pm SD$ (minimum–maximum).

Dia. 1 indicates the diameter of the superior branches' of Tb; Dia. 2, the diameter of the inferior branches of Tb; Dia. 3, the diameter of the superior branches of Tb; Dia 4, the diameter of the intermedium branches of Tb; Dia. 5, the diameter of the inferior branches of Tb; type 1, the Tb divided into 2 branches (superior and inferior branches); type 2, the Tb divided into 3 branches (superior, intermedium and inferior branches).

Fig. 3 The photograph shows the left ventral lateral view. Cr, cranial; D, disk; La, lumbar artery; Lb, lateral branch; Db, dorsal branch; Tb, (white arrow) transverse branch; Deb, descending branch; Ab, ascending branch; Sa, spinal artery; n, nerve root; Tp, transverse process; Sp, superior articular process; Mm, multifidus muscle



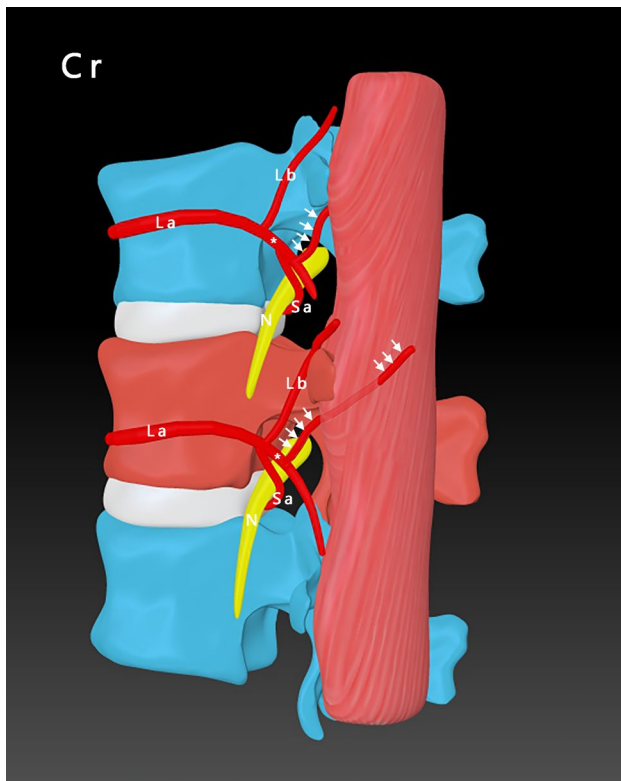


Fig. 4 Left ventral lateral view. This is a simulation diagram of the transverse branch arteries at the L1–L4 intervertebral foramina level described in the text. Cr, cranial; La, lumbar artery; n, nerve root; Lb, lateral branch; Db, (*) dorsal branch; Tb, (white arrow) transverse branch; Sa, spinal artery; Mm, multifidus muscle

beginning, it may be necessary to perform a CTA postoperatively when the condition of the Tb cannot be ascertained.

Based on previous experiments, we have made the following conjectures. Most Tbs are of type 2, and branches of this type have an abundant blood supply. Therefore, when a surgeon uses an electric knife to coagulate the vessel, bleeding occurs, blurring the visual field of operation, especially at the L2–L3 level. If a surgeon can identify and avoid this vessel carefully, the surgical effect may be improved and the incidence of complications made be decreased. Owing to its particular morphology, the Tb is easily damaged in TLIF, especially in TPFs. This damage may cause bleeding and lead to postoperative complications, as PSAs. Therefore, we believe that traditional ligation may be safer and more reliable. Clinicians can select a treatment that is appropriate to the clinical situation by understanding the distribution of the Tbs (Fig. 4).

PSAs is a very rare complication of lumbar spine surgery, with an incidence of 0.08–0.2% [22]. The case of PSA reported by Maurizio et al. occurred 7 days after TLIF, while those reported by Keerthivasan et al. occurred 2 weeks later [4, 5]. It seems that the occurrence of PSAs is delayed, which may cause severe consequences after the patient had

left the hospital. In 1997, Toursarkissian et al. [23] reported that 21-day incidence rate of the thrombosis in PSAs was 88% (72 of 82 PSAs). To our knowledge, some cases of postoperative LA PSA cause psoas hematoma and even cause pressure symptoms on intraspinal neural structures. Additional complications include infections and distal embolization, causing the compression of surrounding structures and dermal and subcutaneous tissue necrosis. PSAs after TLIF are difficult for surgeons to prevent.

Maria et al. [24] reported procedure-related risk factors for PSA, including older age (>75), female sex, underlying diseases, and abnormally high or low artery positions. Ahmad suggested that poor techniques and patient factors were the main factors of PSA [23]. Many studies have suggested that lumbar diseases are more common in elderly individuals and individuals with diabetes and hypertension. In our study, most of the Tbs that passed through the multifidus were of type 2. The exposed end of the Tb was the main branch of its three branches. In TLIF, the muscles usually need to be pulled to the superior and inferior articular processes [2, 25]. The Tb might be wounded and retract into the multifidus quickly because of the tension of the muscle. Electrotomes cannot deal with Tbs in the multifidus. If aggravated, continuous bleeding of the Tbs may cause PSAs.

This study has some limitations, and the main limitation is the lack of practical clinical validation data. Although we believe that the Tb is the main cause of PSAs, we cannot exclude other dorsal branches (Dbs). Therefore, some additional experiments must be conducted in order to provide more information about the branches of the Db and Tb. Due to the relative differences in the positions of blood vessels due to interindividual differences in anatomy, there may be other differences in the Tbs; thus, large sample sizes are needed.

Conclusions

This is an anatomical study of PSAs after TLIF describing the Tbs of dorsal arteries at the L1–L4 levels. In particular, this study describes the quantity, origins, paths and distribution of the Tbs. Surgeons are likely to endanger the Tb when approaching the region of the transverse process, postoperative CTA may be advisable to ensure that the vessel has not been damaged. The present findings highlight the importance of recognizing the Tb as a very important arterial branch in TLIF. A comprehensive understanding of the Dbs and Tbs of the LA will help reduce the occurrence of PSAs and intraoperative bleeding and ensure a clear view of the surgical field during TLIF.

Acknowledgements This study has been supported by grants from The Science and Technology Project of Guangdong (Grant No.

2017B020210010). The study has been supported by grants from Natural Science Foundation of Guangdong (Grant No.2021A1515010864).

Declarations

Conflict of interest There is no potential conflict of interest-associated biases in the text of the manuscript.

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