Surgical Invasiveness of Single-Segment Posterior Lumbar Interbody Fusion: Comparing Perioperative Blood Loss in Posterior Lumbar Interbody Fusion with Traditional Pedicle Screws, Cortical Bone Trajectory Screws, and Percutaneous Pedicle Screws

Tetsuji Inoue, Masaya Mizutamari, Kuniaki Hatake

Department of Orthopaedic Surgery, Kumamoto Chuo Hospital, Kumamoto, Japan

Study Design: Single-center retrospective study.

Purpose: This study aims to evaluate the surgical invasiveness of single-segment posterior lumbar interbody fusion (PLIF) by comparing perioperative blood loss in PLIF with traditional pedicle screws (PS), cortical bone trajectory screws (CBT), and percutaneous pedicle screws (PPS).

Overview of Literature: Intraoperative blood loss has often been used to evaluate surgical invasiveness. However, in patients undergoing spinal surgery, more blood loss is observed postoperatively than intraoperatively. Therefore, evaluating surgical invasiveness using only the intraoperative bleeding volume may result in considerable underestimation of the actual surgical invasiveness.

Methods: This study included patients who underwent single-segment PLIF between January 2012 and December 2017. In total, seven patients underwent PLIF with PS (PS-PLIF), nine underwent PLIF with CBT (CBT-PLIF), and 15 underwent PLIF with PPS (PPS-PLIF).

Results: No significant differences were noted in terms of operation time or intraoperative bleeding between the PS-PLIF, CBT-PLIF, and PPS-PLIF groups. However, the postoperative drainage volume in the PPS-PLIF group (210.1 mL; range, 50–367 mL) was determined to be significantly lower than that in the PS-PLIF (416.7 mL; range, 260–760 mL; *p*=0.002) and CBT-PLIF (421.1 mL; range, 180–890 mL; *p*=0.006) groups. In addition, the total amount of intraoperative bleeding and postoperative drainage was found to be significantly lower in the PPS-PLIF group (362.8 mL; range, 145–637 mL) than in the PS-PLIF (639.6 mL; range, 285–1,000 mL; *p*=0.01) and CBT-PLIF (606.7 mL; range, 270–950 mL; *p*=0.005) groups.

Conclusions: Based on our findings, evaluating surgical invasiveness using only intraoperative bleeding can result in the underestimation of actual surgical invasiveness. Even with single-segment PLIF, the amount of perioperative bleeding can vary depending on the way the posterior instrument is installed.

Keywords: Percutaneous pedicle screw; Perioperative bleeding; Posterior lumbar interbody fusion; Postoperative bleeding; Spine surgical invasiveness

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Introduction

Posterior lumbar interbody fusion (PLIF) or transforaminal lumbar interbody fusion has been considered as the standard surgical procedure for neurological symptoms associated with lumbar degenerative spondylolisthesis and disc degeneration. In recent years, lumbar spinal fusion surgery with less invasion to the paraspinal muscles has been developed in an attempt to reduce postoperative pain and facilitate earlier recovery after surgery. Foley et al. [1] achieved minimal invasiveness by mini-open transforaminal lumbar interbody fusion with percutaneous pedicle screws (PPS). Santoni et al. [2] have also reduced the length of the skin incision and the amount of paraspinal muscle resection using PLIF with cortical bone trajectory screws (CBT-PLIF). At our facility, we first performed PLIF using conventional pedicle screws (PS-PLIF), then with CBT-PLIF, and, most recently, PLIF with PPS (PPS-PLIF).

Surgery time and intraoperative blood loss are often used in determining surgical invasiveness [3-16]. However, in patients undergoing spinal surgery, we often observe more blood loss postoperatively than intraoperatively. Therefore, using intraoperative bleeding amount alone in evaluating surgical invasiveness may underestimate the actual invasiveness of the surgery. Thus, we believe perioperative blood loss, including both intra- and postoperative bleeding, should be taken into consideration to assess surgical invasiveness. In this study, we retrospectively examined the differences in surgical invasiveness between conventional PS-PLIF, CBT-PLIF, and PPS-PLIF with a particular focus on perioperative blood loss.

Materials and Methods

This retrospective study was performed in a single facility. The data were collected from the patients' electronic medical records and were evaluated retrospectively. In total, 91 patients were found to have undergone single-segment PLIF, including decompression of adjacent segments, between January 2012 and December 2017. Of these 91 patients, eight underwent PS-PLIF, 12 underwent CBT-PLIF, and 57 underwent PPS-PLIF. Of the 77 patients who underwent these procedures, we excluded three patients who underwent CBT-PLIF and 19 patients who underwent PPS-PLIF because of their undergoing dialysis. We also excluded non-dialysis patients who underwent revision

surgery (one patient in the PS-PLIF group and 23 in the PPS-PLIF group). Therefore, this present study included seven patients who underwent PS-PLIF, nine patients who underwent CBT-PLIF, and 15 patients who underwent PPS-PLIF. All patients have reportedly undergone surgery for neurological symptoms associated with lumbar degenerative spondylolisthesis and disc degeneration.

The requirement for informed consent from individual patients was omitted because of the retrospective design of this study.

1. Surgical techniques

For PS-PLIF, a bullet-type cage was inserted into the intervertebral bodies after performing laminectomy and medial resection of the bilateral facet joints. The outside was expanded to the transverse process, and the PS was then placed. For CBT-PLIF, the same procedure was used for decompression from the midline and placement of a bullet-type cage into the intervertebral bodies with medial resection of the bilateral facet joints. Screw installation was performed as per the CBT method [2]. For the PPS-PLIF procedure, decompression was performed from the midline, and the facet joints were resected on the symptomatic or symptom-dominant side. A boomerang-type cage was then placed into the intervertebral bodies. A PPS was placed with other incisions in the bilateral paramedian regions.

In all of these three groups, locally harvested bone was used for bone grafting between vertebral bodies. No difference was noted in intraoperative hemostasis among the three groups. Furthermore, no posterolateral fusion was performed in any of the groups.

2. Comparison parameters

These three groups were compared in terms of patient characteristics (sex, age at time of surgery, body mass index, history, or comorbidities [i.e., hypertension, diabetes, cerebral infarction, myocardial infarction, and angina], and use of anticoagulation or antiplatelet medications [i.e., aspirin and warfarin]) and perioperative parameters (preoperative hemoglobin level; preoperative activated partial thromboplastin time; preoperative albumin level; operation time; intraoperative bleeding volume; postoperative drainage volume; total bleeding volume; and postoperative hemoglobin level at 1, 3, and 7 days after

surgery). However, one patient in the CBT-PLIF group who received an intraoperative blood transfusion and one patient in the PS-PLIF group who received a transfusion the day after surgery were excluded from the perioperative blood data comparison. We have also compared perioperative complications and length of hospital stay. Other clinical results were excluded because of lacking data in terms of the Japanese Orthopedic Association scores. The use of closed suction drains for postoperative drainage was also examined.

Statistical analysis was performed using IBM SPSS Statistics ver. 20.0 (IBM Corp., Armonk, NY, USA). Continuous variables were compared using Mann-Whitney U-test, and categorical variables were compared using Fisher's exact probability test. The risk rate was determined to be 5%.

Results

1. Patient characteristics

The male-to-female ratio was 6-to-1 in the PS-PLIF group, 1-to-8 in the CBT-PLIF group, and 7-to-8 in the PPS-PLIF group. A significant difference was observed between the PS-PLIF and CBT-PLIF groups ($p<0.001$). The age at the time of surgery was 61.3 years (range, 48–78 years) in the PS-PLIF group, 67.0 years (range, 32–82 years) in the CBT-PLIF group, and 65.3 years (range, 40–83 years) in the PPS-PLIF group. The body mass index was 24.1 kg/m^2 (range, 19.8–28.4 kg/m^2) in the PS-PLIF group, 22.9 kg/m^2 (range, 18.0–27.9 kg/m^2) in the CBT-PLIF group, and 23.2 kg/m^2 (range, 15.9–32.6 kg/m^2) in the PPS-PLIF group. No significant difference was noted in either parameter between the three groups (Table 1).

2. Medical history and comorbidities

The prevalence of hypertension was determined to be at 7 1% (5 of 7) in the PS-PLIF group, 33% (3 of 9) in the CBT-PLIF group, and 53% (8 of 15) in the PPS-PLIF group. For diabetes, its prevalence rate was found to be 14% (1 of 7) in the PS-PLIF group, 22% (2 of 9) in the CBT-PLIF group, and 20% (3 of 15) in the PPS-PLIF group. The prevalence of angina was 14% (1 of 7) in the PS-PLIF group, 11% (1 of 9) in the CBT-PLIF group, and 13% (2 of 15) in the PPS-PLIF group. For myocardial infarction, its prevalence rate was 0% (0 of 7) in the PS-PLIF group, 11% (1 of 9) in the CBT-PLIF group, and 0% (0 of 15) in the PPS-PLIF group. The prevalence of cerebral infarction was 0% (0 of 7) in the PS-PLIF group, 0% (0 of 9) in the

Table 1. Characteristics of patients undergoing PS-PLIF, CBT-PLIF, and PPS-PLIF

Characteristic	PS-PLIF (n=7)	CBT-PLIF (n=9)	PPS-PLIF (n=15)	p-value
Sex (male:female)	6:1[a]	1:8[a]	7:8	<0.001[a]
Age (yr)	61.3 (48–78)	67.0 (32–82)	65.3 (40–83)	NS
Body mass index (kg/m^2)	24.1 (19.8–28.4)	22.9 (18.0–27.9)	23.2 (15.9–32.6)	NS
Comorbidities				
Hypertension	5 (71)	3 (33)	8 (53)	NS
Diabetes	1 (14)	2 (22)	3 (20)	NS
Angina	1 (14)	1 (11)	2 (13)	NS
Myocardial infarction	0	1 (11)	0	NS
Cerebral infarction	0	0	1 (7)	NS
Medication use				
Aspirin	2 (29)	1 (11)	2 (13)	NS
Warfarin	0	1 (11)	1 (7)	NS
Aspirin/hypertension	2 (29)	1 (11)	1 (7)	NS

Values are presented as number, mean (range), or number (%).
PS-PLIF, posterior lumbar interbody fusion with pedicle screws; CBT-PLIF, posterior lumbar interbody fusion with cortical bone trajectory screws; PPS-PLIF, posterior lumbar interbody fusion with percutaneous pedicle screws; NS, not significant.
[a]Statistically significant difference.

CBT-PLIF group, and 7% (1 of 15) in the PPS-PLIF group. Overall, no significant differences were noted in any co-morbidities between the three groups (Table 1).

3. Anticoagulation and antiplatelet drug use

The rate of aspirin use was determined to be 29% (2 of 7) in the PS-PLIF group, 11% (1 of 9) in the CBT-PLIF group, and 13% (2 of 15) in the PPS-PLIF group. The rate of warfarin use was 0% (0 of 7) in the PS-PLIF group, 11% (1 of 9) in the CBT-PLIF group, and 7% (1 of 15) in the PPS-PLIF group. There was no significant difference in either medication between the three groups. No significant difference was also noted in the proportion of patients with hypertension who were taking aspirin among the PS-PLIF (29% [2 of 7]), CBT-PLIF (11% [1 of 9]), and PPS-PLIF groups (7% [1 of 15]) (Table 1).

4. Perioperative parameters

The preoperative hemoglobin level was 14.2 g/dL (range, 11.6–15.1 g/dL) in the PS-PLIF group, 12.4 g/dL (range,

10.9–15.8 g/dL) in the CBT-PLIF group, and 13.4 g/dL (range, 8.8–15.7 g/dL) in the PPS-PLIF group. A significant difference was noted between the PS-PLIF and CBT-PLIF groups ($p<0.05$). The preoperative activated partial thromboplastin time was 28.6 seconds (range, 21.5–32.9 seconds) in the PS-PLIF group, 29.6 seconds (range, 26.7–33.2 seconds) in the CBT-PLIF group, and 29.8 seconds (range, 21.9–56.2 seconds) in the PPS-PLIF group. The preoperative albumin level was 4.64 g/dL (range, 4.2–5.3 g/dL) in the PS-PLIF group, 4.29 g/dL (range, 3.9–4.7 g/dL) in the CBT-PLIF group, and 4.19 g/dL (range, 3.4–4.8 g/dL) in the PPS-PLIF group. There was no significant difference in either parameter among the three groups (Table 2).

5. Intraoperative parameters

The total number of intervertebral decompression treatments of PLIF-adjacent segments was 1, 1, and 5 in the PS-PLIF, CBT-PLIF, and PPS-PLIF groups, respectively. The surgery time was 202.1 minutes (range, 137–334 minutes), 200.4 minutes (range, 131–264 minutes), and 183.3 minutes (range, 140–237 minutes), respectively. The intra-

Table 2. Perioperative data of patients undergoing PS-PLIF, CBT-PLIF, and PPS-PLIF

Variable	PS-PLIF (n=7)	CBT-PLIF (n=9)	PPS-PLIF (n=15)	*p*-value
Preoperative parameters				
Hemoglobin (g/dL)	14.2 (11.6–15.1)[a]	12.4 (10.9–15.8)[a]	13.4 (8.8–15.7)	<0.05[a]
APTT (sec)	28.6 (21.5–32.9)	29.6 (26.7–33.2)	29.8 (21.9–56.2)	NS
Albumin (g/dL)	4.64 (4.2–5.3)	4.29 (3.9–4.7)	4.19 (3.4–4.8)	NS
Intraoperative parameters				
Additional decompression	1	1	5	
Operative time (min)	202.1 (137–334)	200.4 (131–264)	183.3 (140–237)	NS
Intraoperative blood loss (mL)	222.9 (25–635)	185.6 (50–460)	152.7 (60–305)	NS
Postoperative parameters				
Postoperative drainage volume (mL)	416.7 (260–760)[a]	421.1 (180–890)[b]	210.1 (50–367)[a,b]	0.002[a]/0.006[b]
Total amount of blood loss (mL)	639.6 (285–1,000)[a]	606.7 (270–950)[b]	362.8 (145–637)[a,b]	0.01[a]/0.005[b]
Hemoglobin (g/dL)				
1 Day after surgery	11.96 (8.7–13.2)	10.80 (9.7–14.2)[a]	11.91 (9.3–15.0)[a]	0.04[a]
3 Days after surgery	12.00 (8.6–13.2)	11.19 (9.3–14.4)	11.75 (10.0–14.3)	NS
7 Days after surgery	11.59 (8.3–13.1)	10.49 (9.1–14.4)[a]	11.66 (9.7–14.0)[a]	0.03[a]
Others				
Hospital stay (day)	21.4 (17–25)	20.7 (18–28)	21.7 (15–38)	NS

Values are presented as mean (range). Additional decompression refers to the total number of intervertebral decompression treatments of PLIF-adjacent segments.
PS-PLIF, posterior lumbar interbody fusion with pedicle screws; CBT-PLIF, posterior lumbar interbody fusion with cortical bone trajectory screws; PPS-PLIF, posterior lumbar interbody fusion with percutaneous pedicle screws; APTT, activated partial thromboplastin time; NS, not significant.
[a,b]Statistically significant.

operative bleeding volume was 222.9 mL (range, 25–635 mL), 185.6 mL (range, 50–460 mL), and 152.7 mL (range, 60–305 mL), respectively. There were no significant differences between the three groups (Table 2).

6. Postoperative parameters

The postoperative drainage volume was 416.7 mL (range, 260–760 mL) in PS-PLIF group, 421.1 mL (range, 180–890 mL) in the CBT-PLIF group, and 210.1 mL (range, 50–367 mL) in the PPS-PLIF group. The volume was determined to be significantly lower in the PPS-PLIF group than in the PS-PLIF and CBT-PLIF groups ($p=0.002$ and 0.006, respectively). In addition, the total volume of intraoperative bleeding and postoperative drainage was 639.6 mL (range, 285–1,000 mL) in the PS-PLIF group, 606.7 mL (range, 270–950 mL) in the CBT-PLIF group, and 362.8 mL (range, 145–637 mL) in the PPS-PLIF group. The volume was significantly lower in the PPS-PLIF group compared with that in the PS-PLIF and CBT-PLIF groups ($p=0.01$ and 0.005, respectively). The postoperative hemoglobin level was 11.96 g/dL (range, 8.7–13.2 g/dL),

10.80 g/dL (range, 9.7–14.2 g/dL), and 11.91 g/dL (range, 9.3–15.0 g/dL) in the PS-PLIF, CBT-PLIF, and PPS-PLIF groups, respectively, at 1 day after surgery; 12.00 g/dL (range, 8.6–13.2 g/dL), 11.19 g/dL (range, 9.3–14.4 g/dL), and 11.75 g/dL (range, 10.0–14.3 g/dL), respectively, at 3 days after surgery; and 11.59 g/dL (range, 8.3–13.1 g/dL), 10.49 g/dL (range, 9.1–14.4 g/dL), and 11.66 g/dL (range, 9.7–14.0 g/dL), respectively, at 7 days after surgery. The postoperative hemoglobin level was found to be significantly lower in the CBT-PLIF group than in the PPS-PLIF group at 1 and 7 days after surgery ($p=0.04$ and 0.03, respectively) (Table 2). The length of hospital stay was 21.4 days (range, 17–25 days), 20.7 days (range, 18–28 days), and 21.7 days (range, 15–38 days) in the PS-PLIF, CBT-PLIF, and PPS-PLIF groups, respectively. No significant differences were observed among the three groups.

7. Perioperative complications

The perioperative transfusion rate was 0.0% (0 of 7) in the PS-PLIF group, 11.1% (1 of 9) in the CBT-PLIF, and 6.7% (1 of 15) in the PPS-PLIF group. The reoperation rate for

Table 3. Perioperative complications in patients undergoing PS-PLIF, CBT-PLIF, and PPS-PLIF

Variable	PS-PLIF (n=7)	CBT-PLIF (n=9)	PPS-PLIF (n=15)	*p*-value
Blood transfusion	0	1 (11.1)	1 (6.7)	NS
Reoperation for false screw insertion	0	0	1 (6.7)	NS
Dural injury	0	0	0	NS
Reoperation for epidural hematoma	0	0	0	NS
Reoperation for surgical site infection	0	0	0	NS

Values are presented as number (%).
PS-PLIF, posterior lumbar interbody fusion with pedicle screw; CBT-PLIF, posterior lumbar interbody fusion with cortical bone trajectory screw; PPS-PLIF, posterior lumbar interbody fusion with percutaneous pedicle screw; NS, not significant.

Table 4. Closed suction drains in patients undergoing PS-PLIF, CBT-PLIF, and PPS-PLIF

Variable	PS-PLIF (n=7)	CBT-PLIF (n=9)	PPS-PLIF (n=15)	*p*-value
OrthoPAT (DTD: 5.0 mm)	2 (28.6)	0	0	NS
SB Vac Super Smooth (DTD: 5.0 mm)	1 (14.3)	1 (11.1)	0	NS
SB Vac Super Smooth (DTD: 3.3 mm)	3 (42.9)	8 (88.9)[a]	7 (46.7)[a]	0.048[a]
J-VAC (DTD: 5.0 mm)	1 (14.3)	0[a]	6 (40.0)[a]	0.037[a]
J-VAC (DTD: 3.5 mm)	0	0	2 (13.3)	NS

Values are presented as number (%).
PS-PLIF, posterior lumbar interbody fusion with pedicle screws; CBT-PLIF, posterior lumbar interbody fusion with cortical bone trajectory screws; PPS-PLIF, posterior lumbar interbody fusion with percutaneous pedicle screws; DTD, drain tube diameter; NS, not significant.
[a]Statistically significant.

screw insertion was 0.0% (0 of 7) in the PS-PLIF group, 0.0% (0 of 9) in the CBT-PLOF group, and 6.7% (1 of 15) in the PPS-PLIF group. No significant difference in either parameter was noted between the three groups (Table 3). There were no intraoperative dural injuries, reoperations for epidural hematomas, reoperations for postoperative infections, or other major perioperative complications in any of the three groups.

8. Closed suction drains

The following three types of postoperative closed suction drains were used: OrthoPAT (Haemonetics Corp., Braintree, MA, USA), SB VAC Super-Smooth (Sumitomo Bakelite Co. Ltd., Tokyo, Japan), and J-VAC combined with BLAKE Silicone Drain and J-VAC Suction Reservoir (Johnson & Johnson, New Brunswick, NJ, USA). Table 4 shows the types of drains used in each group. The SB VAC Super-Smooth drain with a 3.3-mm (10F) tube diameter was used most frequently. Therefore, patients in whom this drain tube was used were compared among the three groups to evaluate perioperative blood loss (Table 5). Even with a closed suction drain of the same model and diameter, the postoperative drainage volume was noted to be significantly lower in the PPS-PLIF group (160.0 mL; range, 50–260 mL) than in the PS-PLIF (303.3 mL; range, 260–360 mL) and CBT-PLIF (417.5 mL; range, 180–890 mL) groups (p=0.02 and 0.005, respectively).

Discussion

Surgical invasiveness is usually evaluated based on surgical time and intraoperative bleeding volume [3-16]. However, in this present study, the mean postoperative drainage volume in the PS-PLIF group was more than twice the mean intraoperative blood loss volume, and the difference was determined to be statistically significant ($p<0.05$). In addition, the mean postoperative drainage volume in the CBT-PLIF group was nearly double the mean intraoperative blood loss volume, with a significant difference ($p<0.05$). Takenaka et al. [17] have reported that in patients undergoing interbody fusion using CBT and PS, the postoperative drainage volume was approximately 3 and 2 times the intraoperative blood loss volume, respectively. This is consistent with our results. The higher postoperative drainage volume compared with intraoperative bleeding volume might be explained by the increased muscle blood flow, which can be attributed to its release from the retractor, the change in body position from the prone to supine position, the increased blood pressure associated with recovery from anesthesia, the effect of closed negative-pressure drainage, and the effect of the dead space created by the surgical procedure. Therefore, using only the intraoperative bleeding volume may not be accurate in evaluating actual surgical invasiveness.

In both the PS-PLIF and CBT-PLIF groups, the postoperative drainage volume and the total amount of intraoperative bleeding were significantly greater than those in the PPS-PLIF group; furthermore, the postop-

Table 5. Perioperative data of patients undergoing PS-PLIF, CBT-PLIF, and PPS-PLIF using SB VAC Super-Smooth with 3.33-mm drain tube

Variable	PS-PLIF (n=3)	CBT-PLIF (n=9)	PPS-PLIF (n=8)	p-value
Preoperative parameters				
Hemoglobin (g/dL)	14.5 (13.7–14.9)	12.6 (10.9–15.8)	13.4 (8.8–15.5)	NS
APTT (sec)	26.4 (21.5–32.9)	29.3 (26.7–33.2)	30.3 (21.9–56.2)	NS
Intraoperative parameters				
Operative time (min)	183.7 (169–204)	197.0 (131–264)	196.3 (148–237)	NS
Intraoperative blood loss (mL)	158.3 (25–280)	177.5 (50–460)	147.1 (75–305)	NS
Postoperative parameters				
Postoperative drainage volume (mL)	303.3 (260–360)[a]	417.5 (180–890)[b]	160.0 (50–260)[a,b]	0.02[a]/0.005[b]
Total amount of blood loss (mL)	461.7 (285–570)	595.0 (270–950)[b]	307.1 (145–565)[b]	0.009[b]

Values are presented as mean (range).
PS-PLIF, posterior lumbar interbody fusion with pedicle screws; CBT-PLIF, posterior lumbar interbody fusion with cortical bone trajectory screws; PPS-PLIF, posterior lumbar interbody fusion with percutaneous pedicle screws; NS, not significant; APTT, activated partial thromboplastin time.
[a,b]Statistically significant.

erative drainage volume in both the PS-PLIF and CBT-PLIF groups was approximately double the intraoperative bleeding volume. This is a surprising result considering that no significant difference was noted in the intraoperative bleeding volume among the three groups. This indicates the inappropriateness of using the intraoperative bleeding volume alone in comparing surgery-related blood loss among different procedures.

Although the degree of muscle stripping required for surgery is similar between CBT-PLIF and PPS-PLIF, the current study demonstrated that the amount of postoperative drainage was significantly higher in PS-PLIF and CBT-PLIF with posterior instruments in the drainage space than in PPS-PLIF without posterior instruments at the same site. Therefore, the difference in the postoperative drainage volume among the three groups was considered to be associated with dead space expansion with posterior instruments because of the minimal surgery-related changes in the intervertebral body and medial lamina among the three groups. The surgical invasiveness of PPS-PLIF might be comparable to that of PLIF without PS. In fact, in a study by Park et al. [18], single-vertebral PLIF with PS showed twice the amount of postoperative bleeding as single-vertebral PLIF without PS, which was found to be consistent with this present study. After surgery, rebleeding was observed in the wound as blood pressure increases after withdrawal from anesthesia, but bone and soft tissue in contact with the dead space cannot be expected to induce a hemostatic effect by direct compression. Even if the skin incision length and muscle excision amount are relatively small, extra dead space created by the posterior instrument increases the amount of postoperative drainage, resulting in an increased amount of perioperative bleeding. Therefore, PPS-PLIF, which does not involve the use of posterior devices in the same compartment, is considered the most advantageous of the three procedures in terms of reducing perioperative bleeding. PPS-PLIF is also useful for patients who require the lowest amount of bleeding possible, such as patients with heart failure, patients with anemia, and patients undergoing dialysis [19].

With regard to postoperative soft tissue repair, a larger dead space and the instrument that forms it are associated with a risk of postoperative infection and are, therefore, clearly disadvantageous compared with the absence of instruments in a smaller dead space. A PPS covered with blood flow-rich muscle tissue is relatively resistant to

postoperative infection. If it does become infected, it is located within a separate compartment from the anterior instrument, and the infection does not readily spread to the anterior compartment. Cizik et al. [20] used a surgical invasiveness index that evaluates the risk of surgical site infection. Although all three groups had the same number of points in their study, the risk of surgical site infection is never the same. Liu et al. [21] found that postoperative hemoglobin reduction was a risk factor for postoperative surgical site infection and that reducing perioperative blood loss may be useful in preventing such infection. In this present study, the hemoglobin level was found to be significantly lower on postoperative days 1 and 7 in the CBT-PLIF than in the PPS-PLIF group, which may reflect the difference in postoperative bleeding. However, three days after surgery, there was no significant difference between these two groups. Although PPS-PLIF is considered to have an advantage in terms of a lower postoperative infection rate, no postoperative infection occurred among the three groups this study.

Our study has several limitations. First, the number of patients included in this study was very small, and it was a retrospective study conducted at a single center. Therefore, the study was statistically underpowered for complications that are not particularly frequent. However, even in this small patient population, the postoperative drainage volume and perioperative bleeding volume were determined to be significantly higher in the PS-PLIF and CBT-PLIF groups (with a posterior instrument in the same compartment as the anterior instrument) than in the PPS-PLIF group (with a posterior instrument in a different compartment than the anterior instrument). Second, the postoperative effluent was only part of the postoperative bleeding volume, and the hematoma remaining in the dead space formed by the surgery could not be evaluated. However, the remaining hematoma was predicted to be proportional to the size of the dead space and was not expected to affect the results. Third, the hematoma around the PPS was not evaluated. The dead space around the PPS is expected to be overwhelmingly smaller than the dead space formed by exfoliating the muscle from the bone. However, this result has to be verified in future studies. Although the PS-PLIF, CBT-PLIF, and PPS-PLF groups all had the same score using the invasiveness index established by Mirza et al. [22], this present study showed that the three surgical methods do not have the same surgical invasiveness as indicated by perioperative blood

loss. In the case of long fusions, this difference is expected to become larger and affect perioperative complications, which will in turn greatly assist in making surgical decisions.

Conclusions

Evaluating surgical invasiveness using only the intraoperative bleeding amount can result in the underestimation of actual surgical invasiveness. Even with single-segment PLIF, the amount of perioperative bleeding can vary depending on the way the posterior instrument is installed.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

Acknowledgments

References

1. Foley KT, Holly LT, Schwender JD. Minimally invasive lumbar fusion. Spine (Phila Pa 1976) 2003;28(15 Suppl):S26-35.
2. Santoni BG, Hynes RA, McGilvray KC, et al. Cortical bone trajectory for lumbar pedicle screws. Spine J 2009;9:366-73.
3. Kim KT, Lee SH, Suk KS, Bae SC. The quantitative analysis of tissue injury markers after mini-open lumbar fusion. Spine (Phila Pa 1976) 2006;31:712-6.
4. Park Y, Ha JW. Comparison of one-level posterior lumbar interbody fusion performed with a minimally invasive approach or a traditional open approach. Spine (Phila Pa 1976) 2007;32:537-43.
5. Dhall SS, Wang MY, Mummaneni PV. Clinical and radiographic comparison of mini-open transforaminal lumbar interbody fusion with open transforaminal lumbar interbody fusion in 42 patients with long-term follow-up. J Neurosurg Spine 2008;9:560-5.
6. Peng CW, Yue WM, Poh SY, Yeo W, Tan SB. Clinical and radiological outcomes of minimally invasive versus open transforaminal lumbar interbody fusion. Spine (Phila Pa 1976) 2009;34:1385-9.
7. Tsutsumimoto T, Shimogata M, Ohta H, Misawa H. Mini-open versus conventional open posterior lumbar interbody fusion for the treatment of lumbar degenerative spondylolisthesis: comparison of paraspinal muscle damage and slip reduction. Spine (Phila Pa 1976) 2009;34:1923-8.
8. Shunwu F, Xing Z, Fengdong Z, Xiangqian F. Minimally invasive transforaminal lumbar interbody fusion for the treatment of degenerative lumbar diseases. Spine (Phila Pa 1976) 2010;35:1615-20.
9. Wang J, Zhou Y, Zhang ZF, Li CQ, Zheng WJ, Liu J. Comparison of one-level minimally invasive and open transforaminal lumbar interbody fusion in degenerative and isthmic spondylolisthesis grades 1 and 2. Eur Spine J 2010;19:1780-4.
10. Seng C, Siddiqui MA, Wong KP, et al. Five-year outcomes of minimally invasive versus open transforaminal lumbar interbody fusion: a matched-pair comparison study. Spine (Phila Pa 1976) 2013;38:2049-55.
11. Phan K, Rao PJ, Kam AC, Mobbs RJ. Minimally invasive versus open transforaminal lumbar interbody fusion for treatment of degenerative lumbar disease: systematic review and meta-analysis. Eur Spine J 2015;24:1017-30.
12. Phan K, Ramachandran V, Tran TM, et al. Systematic review of cortical bone trajectory versus pedicle screw techniques for lumbosacral spine fusion. J Spine Surg 2017;3:679-88.
13. Kasukawa Y, Miyakoshi N, Hongo M, Ishikawa Y, Kudo D, Shimada Y. Short-term results of transforaminal lumbar interbody fusion using pedicle screw with cortical bone trajectory compared with conventional trajectory. Asian Spine J 2015;9:440-8.
14. Lee GW, Son JH, Ahn MW, Kim HJ, Yeom JS. The comparison of pedicle screw and cortical screw in posterior lumbar interbody fusion: a prospective randomized noninferiority trial. Spine J 2015;15:1519-26.
15. Sakaura H, Miwa T, Yamashita T, Kuroda Y, Ohwada T. Posterior lumbar interbody fusion with cortical bone trajectory screw fixation versus posterior lumbar interbody fusion using traditional pedicle screw fixation for degenerative lumbar spondylolisthesis: a comparative study. J Neurosurg Spine 2016;25:591-5.
16. Hu W, Tang J, Wu X, Zhang L, Ke B. Minimally in-

vasive versus open transforaminal lumbar fusion: a systematic review of complications. Int Orthop 2016;40:1883-90.

17. Takenaka S, Mukai Y, Tateishi K, Hosono N, Fuji T, Kaito T. Clinical outcomes after posterior lumbar interbody fusion: comparison of cortical bone trajectory and conventional pedicle screw insertion. Clin Spine Surg 2017;30:E1411-8.

18. Park JH, Ahn Y, Choi BS, et al. Antithrombotic effects of aspirin on 1- or 2-level lumbar spinal fusion surgery: a comparison between 2 groups discontinuing aspirin use before and after 7 days prior to surgery. Spine (Phila Pa 1976) 2013;38:1561-5.

19. Inoue T, Mizutamari M, Fukuda K, Hatake K. Postoperative complications in dialysis-dependent patients undergoing elective decompression surgery without fusion or instrumentation for degenerative cervical or lumbar lesions. Spine (Phila Pa 1976) 2018;43:1169-75.

20. Cizik AM, Lee MJ, Martin BI, et al. Using the spine surgical invasiveness index to identify risk of surgical site infection: a multivariate analysis. J Bone Joint Surg Am 2012;94:335-42.

21. Liu JM, Deng HL, Chen XY, et al. Risk factors for surgical site infection after posterior lumbar spinal surgery. Spine (Phila Pa 1976) 2018;43:732-7.

22. Mirza SK, Deyo RA, Heagerty PJ, et al. Development of an index to characterize the "invasiveness" of spine surgery: validation by comparison to blood loss and operative time. Spine (Phila Pa 1976) 2008;33:2651-61.