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*Original Article*

# Is Proximal Triangular Fixation Better than the Conventional Method in Adult Spinal Deformity Surgery?

**Masato Tanaka*, Umesh Meena, Takuya Taoka, Yoshihiro Fujiwara, Daiichiro Yokomizo, Santosh Kumar Bashyal, Naveen Sake, and Shinya Arataki**

*Department of Orthopaedic Surgery, Okayama Rosai Hospital, Okayama 702-8055, Japan*

**In adult spinal deformity (ASD) surgery, one of the key factors working to prevent proximal junctional kyphosis is the proximal anchor. The aim of this study was to compare clinical and radiographic outcomes of triangular fixation with conventional fixation as proximal anchoring techniques in ASD surgery. We retrospectively evaluated 54 patients who underwent corrective spinal fusion for ASD. Fourteen patients underwent proximal triangular fixation (Group T; average 74.6 years), and 40 patients underwent the conventional method (Group C; average 70.5 years). Clinical and radiographic outcomes were assessed using visual analogue scale (VAS) values for back pain and the Oswestry disability index (ODI). Radiographic evaluation was also collected preoperatively and postoperatively. Surgical times and intraoperative blood loss of the two groups were not significantly different (493 vs 490 min, 1,260 vs 1,173 mL). Clinical outcomes such as VAS and ODI were comparable in the two groups. Proximal junctional kyphosis in group T was slightly lower than that of group C (28.5% vs 47.5%, $p = 0.491$). However, based on radiology, proximal screw pullout occurred significantly less frequently in the triangular fixation group than the conventional group (0.0% vs 22.5%, $p = 0.049$). Clinical outcomes in the two groups were not significantly different.**

**Key words:** adult spinal deformity, proximal junctional kyphosis, triangular fixation, minimally invasive surgery, C arm free

Adult spinal deformity (ASD) is a relatively common condition and is known to affect and disturb quality of life. Patients with ASD present symptomatology of severe low back pain and symptoms affecting lower limbs such as radicular pain, weakness, and loss of sensation [1]. In recent years, ASD has grown to become a worrisome concern for the aging population, and conservative management has been demonstrably ineffective in severe cases [2]. However, deformity correction surgery for aged patients carries enormous risk because of its relatively high mortality rate (2.4%) and very high complication rate (up to 70%) [3,4]. Minimally invasive surgery (MIS) for spinal fusion has proven to be the best solution for this condition [5]. By implementing the MIS technique for ASD, the incidence rate of the complications has been remarkably reduced [6].

Previously reported complications for ASD surgery include proximal junctional kyphosis (PJK) [7], proximal junctional failure (PJF) [8], implant failure, surgical site infection, and neurological deficit [9], with the incidence of PJK being very high (20-40%) [1]. Various methods have been deployed to prevent PJK, including the use of augmented screws [10], proximal bone cement injection [11], taping [12], and hooks [13]. In 2022, the authors reported a technique of triangular

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*Corresponding author. Phone: +81-86-262-0131; Fax: +81-86-262-3391
E-mail: tanaka0896@gmail.com (M. Tanaka)

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fixation to prevent proximal screw pullout [14]. With this technique, the proximal screw anchor complex is particularly strong as it attaches to two vertebrae in a triangular shape. The aim of this study was to retrospectively compare clinical and radiographic outcomes of proximal triangular fixation with conventional fixation using proximal screw anchors in ASD surgery.

## Materials and Methods

This research was approved by the ethics committee of our institution (No. 306), and informed consent from patients undergoing surgery was duly obtained. A retrospective evaluation was done for the cohort of 54 patients who underwent corrective surgery for ASD at our hospital in the time frame between October 2019 and January 2022. Criteria of inclusion in this research were as follows: age 60 years or older with established findings of at least one of the following: a sagittal vertical axis (SVA) of 95 mm or more, pelvic tilt (PT) of 30 degrees or greater, and/or coronal Cobb angle 30 degrees or greater [3]. Criteria for exclusion were deformities of the spine which occurred as sequelae of neuromuscular pathology, acute or chronic infections of the spine, and/or onco-pathologies. Two-stage operative procedures were performed as planned: first oblique lumbar interbody fusion (OLIF) L1 to L5 or L1 to S1 (OLIF51), then posterior spinal corrective fusion from T10 to the pelvis including the primary transforaminal lumbar interbody fusion (TLIF) at L5-S1 (TLIF51). We changed the procedure in April 2021 because we encountered the problem of proximal screw pullout.

In the cohort, fourteen patients underwent triangular fixation (Group T) and 40 patients underwent conventional fixation (Group C) (Table 1). Group T included 1 male and 13 female patients (average 74.6 ± 3.2 years), while group C included 3 male and 37 female patients (average 70.5 ± 6.6 years). The mean follow-up period for Group T was 20.6 ± 7.4 months and that for Group C was 28.6 ± 9.4 months, with a range of 12 to 43 months. The data and demographics are represented in Table 1.

***Operation procedure.***

***First surgery (OLIF L1-S1)*** (Fig.1) [9].

After general anesthetic induction, the patient was turned to the right lateral decubitus posture on a hinged modifiable carbon fiber operation table (OSI Axis Jackson table; Mizuho, Union City, CA). An O-arm scan was done to obtain 3D computer tomography (CT) imaging. The reference frame for navigation was attached percutaneously over the sacroiliac joint. Ideally, neuro-monitoring is not mandatory when OLIF is performed; nevertheless, at our hospital use of neuro-monitoring is done for all cases to assess neurological status and avoid complications during the procedure. Three appropriate skin incisions of 4-5 cm each were required for this procedure: one to access the levels L1-L2 and L2-L3, the second for L3-L4 and L4-L5, and the third for L5-S1. Cages were inserted in the proximal to distal direction, from L1-2 to L5-S1 in order. A single O arm scan is sufficient to obtain the necessary mapping of the spine required to perform this technique.

***Second surgery (T10-SAI)*** (Fig.2). In the following week, the patient underwent the secondary procedure. After general anesthetic induction, the patient was positioned in the prone position on an Axis Jackson operation table. The navigation reference frame was mounted over the T11 spinous process. An O-arm scan was performed from T10 to L3. Verification of all instruments was done with the navigation system. If pelvic incidence (PI)-lumbar lordosis (LL) after the first surgery was less than 25 degrees, percutaneous pedicle screws (PPS) were introduced and placed by navigation guidance. If PI-LL after the first surgery was less than 25 degrees, open posterior osteotomy was performed. For triangular fixation, transdiscal screws were aimed at

Table 1 Patient demographics

| Group | Proximal fusion | Age (year) | Patients | L5-S1 Interbody Fusion (+/−) | Follow-up (month) |
|---|---|---|---|---|---|
| Group T (n = 14) | Triangular pedicle screw fixation | 74.6 ± 3.2 | Man 1<br>Woman 13 | 14/0 | 20.6 ± 7.4 |
| Group C (n = 40) | Conventional pedicle screw fixation | 70.5 ± 6.6 | Man 3<br>Woman 37 | 38/2 | 28.6 ± 9.4 |

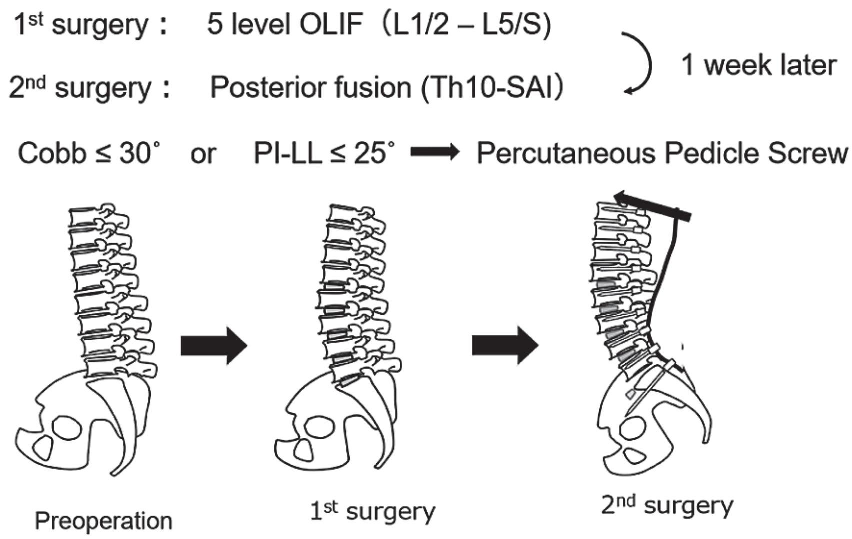


**Fig. 1** Two stage surgeries for adult spinal deformity.

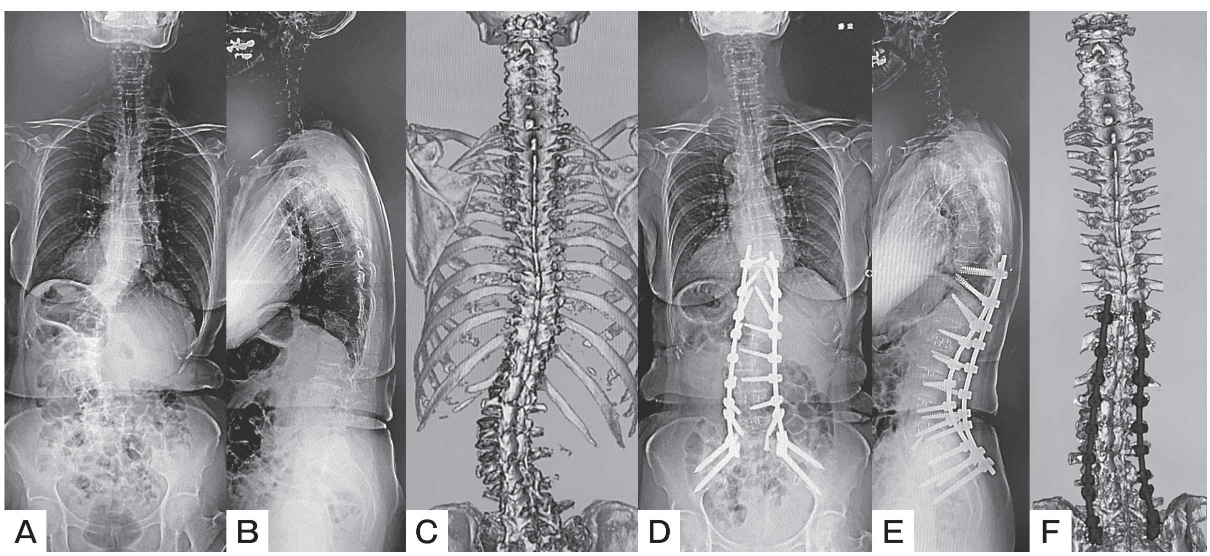


**Fig. 2** 79 years old female, adult spinal deformity of the lumbar spine, OLIF L1-S1 with T10-SAI Instrumentation. **A**, Postero-anterior view radiograph of whole spine taken before surgery; **B**, Lateral view radiograph of the whole spine taken before surgery; which showed severe sagittal malalignment; SVA of 72 mm, PT of 33°, PI-LL of 15°; **C**, Preoperative CT Imaging with 3D reconstruction; **D**, Postero-anterior view radiograph of the whole spine taken after the surgery; **E**, Lateral view radiograph of the whole spine taken after the surgery. Which showed the correction of the sagittal malalignment; SVA of 29 mm, PT of 17°, PI-LL of 0°; **F**, Postoperative CT imaging with 3D reconstruction.

the upper endplate and directed approximately 25 degrees cranially to penetrate the superior endplate of T11, and a T10 PPS was inserted with a lower angulation trajectory (Fig. 3). The spinal navigation was very useful to avoid screw malposition. It is known that the transdiscal pedicle screw should not have an angle more than 30 degrees because this increases pedicle perforation, and the rod doesn't fit the screw head despite its multiaxial mechanism. If a 3rd rod is necessary to enhance the stability, a mini open technique was used to connect the 3rd rod.

Bilateral dual sacral-alar-iliac (SAI) screws have been

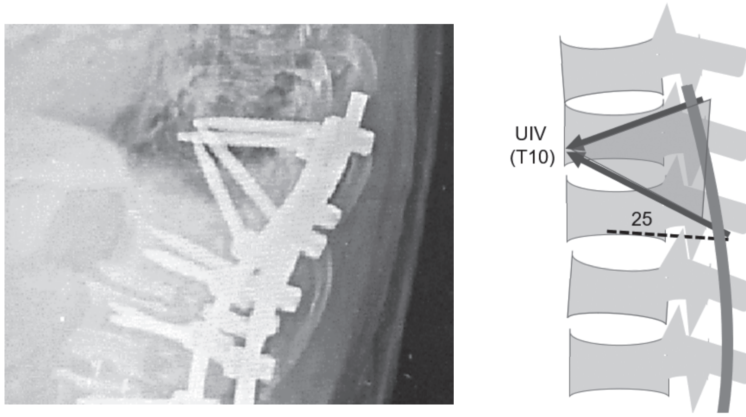


Fig. 3 Triangular fixation. Percutaneous transdiscal screws were aimed upper endplate and directed approximately 25 degrees cranially to penetrate superior endplate of T11. And T10 PPS was inserted with lower angulation trajectory.

advocated to augment the construction of the pelvis [2]. Bilateral rods were curved in an appropriate contour and introduced percutaneously. The Axis Jackson operation table was bent to a > 20 degrees concave position to create adequate lordosis at the lumbar spine. The set screws were then gradually secured to create the expected lumbar lordosis.

***Clinical evaluation.*** The cohort of patients was clinically assessed by using standard quantifiable frames such as the visual analogue scale (VAS) for low back ache and the Oswestry disability index (ODI) for daily living activity. The clinical data were documented preoperatively and at time periods of 6, 12, and 24 months following surgery. Surgical duration, blood loss in milliliters, and any complications in either the intra or postoperative period, such as dural tears, focal sensory motor deficits, surgical site infection, hematoma causing neural compromise, need for revision surgery and implant malposition or failure were noted.

***Radiographic evaluation.*** The following calculations were made of the radiological factors and outcomes were determined: SVA, PI-LL, PT, PJK, and screw pullout presenting in a standing radiogram of lateral view of the whole spine. PJK was defined as a proximal junctional sagittal Cobb angle between the lower endplate of the uppermost instrumented vertebra (UIV) and the upper endplate of 2 supra-adjacent vertebrae ≥ 10° or at least 10° greater than the preoperative measurement [15].

Proximal screw loosening and pullout (> 5 mm) were evaluated in individual groups of the cohort in the postoperative follow-up period, utilizing data from radiograms and CT (Fig. 4). Solid fusion was evaluated as "no instability" in radiograms and "no clear zone" or "bony trabecular connection between the vertebrae" on CT.

***Statistical evaluation.*** All the data collected were expressed as means ± standard deviations (SDs). In comparing the groups, the Mann-Whitney *U* test analysis was used for continuous variables, and the chi-squared test and Fisher's exact test for dichotomous variables. McNemar's test has been used to compare the *p* values. A $p$ value $< 0.05$ was defined as analytically significant.

## Results

***Clinical data evaluation.*** Postoperative clinical data are summarized in Table 2. L5-S1 interbody fusion was not performed in two cases in group C. Posterior percutaneous pedicle screw fixation was applied to 9 cases in group T and 20 cases in group C. The difference in the mean surgical times in groups T and C (493 ± 54.8 min vs. 490 ± 94.4 min, respectively) was statistically insignificant ($p = 0.541$). Likewise, intraoperative blood loss in groups T and C (1,260 ± 824 mL and 1,173 ± 594 mL, respectively) was not significantly different ($p = 0.495$). No statistical differences were observed in ODI score ($p = 0.131$) or VAS back score ($p = 0.198$) between the two groups. SSI, dural tear, epidural hematoma, and the neurological deterioration rate of the two groups were not significantly different. Revision surgery was needed for 2 patients in group T and 8 patients in group C. These were due to deep SSI

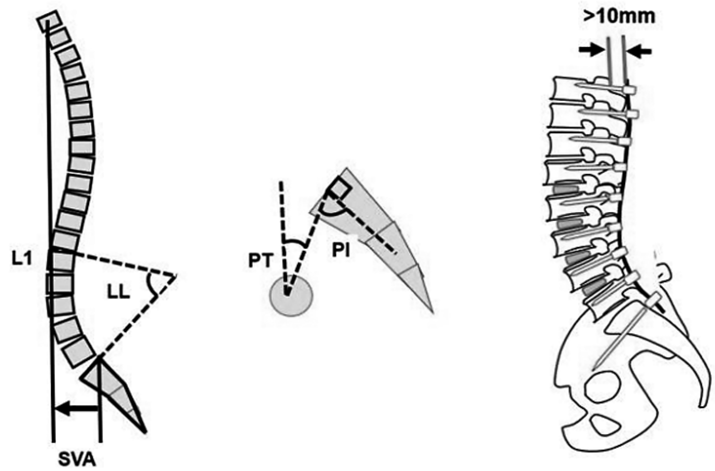


**Fig. 4** Spinopelvic parameters and evaluation of proximal screw pullout. Sagittal vertical axis (SVA), pelvic incidence (PI)-lumbar lordosis (LL), pelvic tilt (PT), Screw loosening and pullout of more than 10 mm is evaluated.

**Table 2** Clinical results of both groups

| | Group T (n=14) | Group C (n=40) | *P*-value |
|---|---|---|---|
| L5-S1 Interbody Fusion (+/−) | 14/0 | 38/2 | 0.460 |
| PPS (+/−) | 9/5 | 20/20 | 0.188 |
| Surgical time (minutes) | 493 ± 54.8 | 490 ± 94.4 | 0.541 |
| Blood loss (mL) | 1,260 ± 824 | 1,173 ± 594 | 0.495 |
| Postoperative ODI (%) | 22.4 ± 17.4 | 38.5 ± 20.4 | 0.198 |
| Postoperative VAS (mm) | 22.5 ± 6.5 | 39.8 ± 7.4 | 0.198 |
| Complication | | | |
| SSI (+/−) | 1/13 | 2/38 | 0.763 |
| Dural tear (+/−) | 0/14 | 1/39 | 0.550 |
| Epidural hematoma (+/−) | 0/14 | 1/39 | 0.550 |
| Neurological deterioration (+/−) | 1/14 | 2/38 | 0.763 |
| Revision surgery (+/−) | 2/12 | 8/32 | 0.636 |

PPS, Percutaneous pedicle screw; ODI, Oswestry disability index; VAS, visual analog scale; SSI, surgical site infection.

in 3 cases, epidural hematoma in 1 case, screw pullout/PJF in 3 cases, and rod breakage in 3 cases.

***Radiographic evaluation.*** Radiographic results are summarized in Table 3. Solid bony fusions at final follow-up were observed in all cases. Postoperative SVA, PI-LL, and PT were improved postoperatively in both groups. We also observed the frequently reported sequela, PJK, in both groups: less frequently in group T (28.5%) than group C (47.5%) but not significantly so ($p=0.216$). Rod breakage, another undesirable incident, was noted in very few participants of both groups (7.15 vs 5.0%, respectively), again with no significant difference ($p=0.763$). Proximal screw pullout was not seen in group T, but several participants with this issue

Table 3 Radiographic results of both groups

| | Group T (n = 14) | Group C (n = 40) | *P*-value |
|---|---|---|---|
| Preoperative SVA (mm) | 108 ± 64.3 | 92.1 ± 52.8 | 0.586 |
| Postoperative SVA (mm) | 48.5 ± 37.9 | 15.5 ± 36.1 | 0.008* |
| Preoperative PI-LL (°) | 46.6 ± 19.5 | 36.7 ± 22.7 | 0.119 |
| Postoperative PI-LL (°) | 7.4 ± 8.9 | 0.58 ± 13.3 | 0.047* |
| Preoperative PT (°) | 38.9 ± 8.5 | 33.0 ± 11.5 | 0.060 |
| Postoperative PT (°) | 25.6 ± 6.7 | 14.2 ± 9.7 | 0.0001** |
| PJK (+/−) | 4/10 (28.5%) | 19/21 (47.5%) | 0.216 |
| Rod breakage (+/−) | 1/13 (7.1%) | 2/38 (5.0%) | 0.763 |
| Proximal screw pullout (+/−) | 0/14 (0.0%) | 9/31 (22.5%) | 0.049* |

SVA, sagittal vertical axis; PI, pelvic incidence; LL, lumbar lordosis; PT, pelvic tilt; PJK, proximal junctional kyphosis. *$p < 0.05$, **$p < 0.01$.

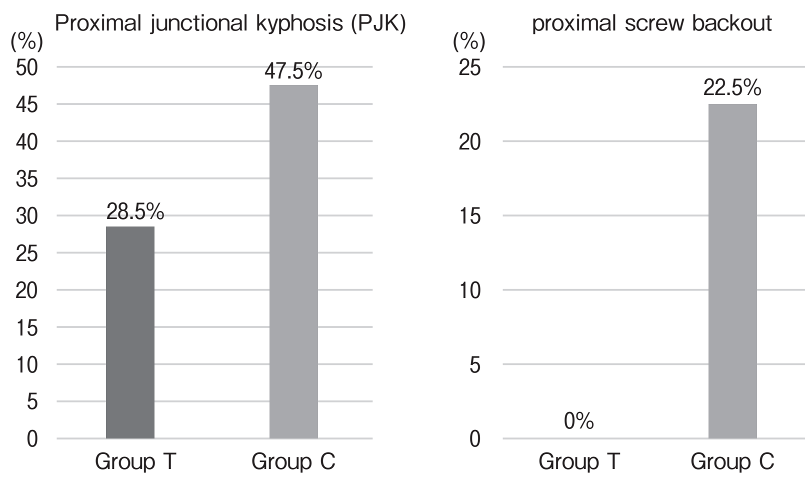


Fig. 5 Proximal junctional kyphosis and proximal screw backout in both groups.

were reported in group C (22.5%) ($p = 0.049$) (Fig. 5). There was no pullout case more than 20 months after surgery in either group. We performed revision surgery for cases with pullout, and solid bony fusions were obtained at the final follow-up in all cases.

## Discussion

Cumulative degenerative changes that come with aging are the major cause of ASD, and degenerative bone and soft-tissue alterations can lead to radiculopathy or instability, which can lead to spinal stenosis [16]. The first step in the degenerative process is a loss of impact absorption in the intervertebral discs. Following this, the pathological changes that occur in the vertebral and facet joints cause an increase in the load placed on the anterior parts of the vertebral joints [16-18]. The incidence of ASD has been reported as very high, but a definitive algorithm for ASD management does not currently exist. Surgical correction of spinal deformity requires thorough planning and careful selection of patients with great attention to detail. ASD surgery is typically accompanied by lengthy periods of recuperation, high rates of complications, and considerable financial outlays.

Corrective surgeries can be performed to primarily target the following: PT 20°, PI-LL mismatch 20°, and SVA 50 mm as the optimal spinopelvic alignment parameters [19]. With the advent of MIS, there has been significant progress in the field of ASD surgery. Circumferential MIS (cMIS), which is a combination of LLIF and PPS, has led to less blood loss, fewer problems, and earlier patient recovery compared to traditional techniques [20]. Unfortunately, the sagittal plane correction that is achieved with cMIS is often insufficient in severe deformity. Anand *et al.* found that in order to obtain a PI-LL of 10° with cMIS, a preoperative PI-LL mismatch should be 38° or less, and a preoperative SVA should be no more than 100 mm [21]. Thus, cMIS can be said to have a ceiling effect. The MIS approach was included in the list of possible surgical techniques for ASD by Mummaneni *et al.* [22]. After that, they suggested a further simplified least-invasive spinal deformity surgery protocol based on the Scoliosis Research Society-Schwab classification modifier [23]. They also reported limitations in the ability of MIS to correct ASD. According to their findings, cases that had an SVA of more than 70 mm, a PT of more than 25 degrees, an LL-PI mismatch of more than 30 degrees, and a thoracic kyphosis of more than 60 degrees on a preoperative plain radiograph should be managed using a conventional posterior osteotomy procedure.

Our two-stage surgery entailed more than 1,000 mL blood loss and required more than 7 hours' surgical time. However, three-column osteotomy has been reported to entail massive blood loss (more than 1,800 mL) and more than 8 h, respectively [24, 25]. Moreover, pedicle subtraction osteotomy (PSO) carries a high risk of neurologic injury (14.7%) compared with multiple OLIF and posterior fusion (2.9%) [26]. A recently established form of MIS known as OLIF has lately gained widespread acceptance worldwide [20, 23]. Mayer reported mini anterior lumbar interbody fusion (mini ALIF) procedure, which was first performed in 1997 [27]. This allowed surgeons to access the lateral area of the spine. Silvestre *et al.* later updated the approach, formally proposing OLIF via MIS, entering the disc space through a corridor between the peritoneum and the psoas muscle [28]. OLIF provides numerous advantages over previous lateral approaches, including a shorter surgery time, less blood loss, a speedier recovery, and a shorter hospital stay [28, 29]. The OLIF procedure takes advantage of an open window between the anterior vessels and the psoas muscle to reach the lumbar spine, which theoretically helps surgeons avoid damaging neighboring essential tissue structures, such as the anterior abdominal major blood arteries and the ureters [30, 31]. Also, because OLIF does not reach the spinal canal or impinge on posterior structures, it has lesser risk of nerve root injury and bleeding in the venous plexus [30]. This is in contrast to posterior lumbar interbody fusion (PLIF) and TLIF, both of which do enter the spinal canal. In addition, unlike direct lumbar interbody fusion (DILF), OLIF does not separate or penetrate the psoas muscle; this prevents any damage to the muscle as well as the lumbar plexus nerve [32].

In this study, the rate of reoperation was relatively high. The cause was deep SSI in 3 cases, epidural hematoma in 1 case, screw pullout/PJF in 3 cases, and rod breakage in 3 cases. Among the reported complications for ASD surgery, incidence of PJK is very high (20-40%) [1]. There have been reported methods to prevent PJK such as augmented screw [10], proximal bone cement injection [11], taping [12], hook [13], and triangular fixation [14]. As the strength of the triangular design depends on the amount of bone between the hardware engagement points rather than only screw purchase, it provides a stronger fixation [33]. Moreover, the pullout force is only slightly impacted by the insertion angle in osteoporotic bone. The insertion angle, which depends on the bone's material characteristics and the length of the screw engagement, has no discernible impact on insertion torque [34]. Hence, longer screws provide better grip. The fact that substantially more bone is accessible cranial to the screw surface to resist the screw cut-out is another benefit of inserting the UIV screw cranio-caudally. We suggest that adoption of comparable procedures may dramatically lower the rates of problems linked to bone-implant contact and, consequently, the incidence of screw pullout. This technique has all these benefits without adding difficulties or cost, and it is applicable to MIS.

In the current study, proximal screw pullout was significantly less frequent among the triangular fixation group (0%) compared to the convention fixation group (22.5%). Soft tissue injuries and postoperative difficulties related to open surgery can be reduced with the introduction of percutaneous pedicle screw fixation using MIS principles [35]. The incidence of PJK in group T was also lower than that of group C. This is partly because the percentage of posterior PPS fixation in group T was higher than that of group C. This may also have helped prevent PJK in group C. Several methods have been suggested to lower the likelihood of screw pullout. Expandable screws provide an 60% greater pullout strength than conventional pedicle screws; however, their price and availability are still major limitations. Moreover, open fixations are the major use for these screws [36]. While bicortical screws are 26% stronger and longer than conventional pedicle screws, their use involves a significant risk of harming the great arteries that are located anteriorly [37] (Table 4). Finally, several recent reports have recommended the use of teriparatide to reduce screw pullout [38, 39].

In present research, postoperative ODI (%) and postoperative VAS (mm) were slightly lower among the triangular fixation group compared to convention fixation but without statistical difference. Tanaka *et al.* [14] showed that at 1-year follow-up, the ODI had improved from 56 to 24% and the VAS score for lower back pain decreased from 62 mm to 24 mm among subjects with undergoing triangular fixation in their ASD surgery. In our study, PJK was a somewhat less common among the triangular fixation group (28.5%) than the conventional fixation group (47.5%). The proximal screw pullout rate was significantly lower among the triangular fixation group (0%) compared to convention fixation (22.5%). During ASD surgery, neurologic problems are not uncommon [40, 41]. Lenke *et al.* [40] found PJF rates of 10.8%, whereas Smith *et al.* [4] observed neurological problems rates of 27.8% after two years following adult spinal deformity correction surgery. According to the previous study by Hamilton *et al.* [41], 7.9% of patients who underwent open deformity correction required reoperation due to neurologic sequelae, compared to 1.6% in the cMIS group and 11.1% in a hybrid group.

Table 4 Various methods to enhance pullout strength of screws (from reference 14).

| Category | Methods | Pullout strength |
|---|---|---|
| Screw design | Expandable screws | 60% up |
| | Augmented screws | >86% up |
| Screw length | Bicortical screws | >26% up |
| Screw diameter | Bigger screws | |
| Screw direction | Cortical bone trajectory | 28% up |
| | Straight-forward screws | 27% up |
| | Transdiscal screws | >60% up |

This study has several limitations. Triangular fixation has potential risks such as screw breakage, malpositioning, or inadequate interface between the screw and rod. The number of patients undergoing triangular fixation (group T) was small. The follow-up period of group C was slightly shorter than that of group T. A biomechanical study should be considered in the future to provide a better picture of the efficacy of triangular fixation. The randomization of participants in a larger prospective study is attractive from the standpoint of data analysis, but this idea is complicated by the need to take into consideration the surgical expertise of the surgeons who would take part in the study, as well as the challenge of obtaining the level of expertise required to conduct the study ethically.

In conclusions, clinical and surgical outcomes of group T (triangular fixation) were not significantly different from those of group C (conventional fixation). However, radiographic outcomes indicated that one clear benefit of triangular fixation was the reduction of proximal screw pullout (0% in group T compared with 22.5% in group C). Minimally invasive triangular fixation is a safe and effective technique that enhances proximal screw anchoring. This new procedure can reduce PJF compared with conventional techniques.

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