Egyptian Journal of Orthopaedic Research "*EJOR*"
An international peer-reviewed journal published bi-annually

Volume 4, Issue 2, Dec. - 2023: pp: 53-62 www.ejor.sohag-univ.edu.eg

Doi: 10.21608/ejor.2023.346402

Original Article

SURGICAL TREATMENT FOR LOW-GRADE SPONDYLOLISTHESIS: CASE SERIES

Ahmed Abdellatif

Orthopedic dept., Faculty of Medicine, Aswan Univ., New Aswan City, Egypt

E-mail: Ahmedsayed1977aswan@gmail.com

Received 1/8/2023 Accepted 22/11/2023

Abstract

Background: *Assessing the clinical, functional, and radiological results of transforaminal lumbar interbody fusion (TILF) with OPAL spacer system cage and expedium 5.5 titanium screw system for low grade spondylolisthesis (Grade I, II).* ***Method:*** *At the Aswan University Hospital at EGYPT, we evaluated 30 patients who had surgery between June 2018 and October 2022. The expedium 5.5 titanium system and OPAL cages were used throughout the operations on all patients. The surgery was performed at L4-5 level in 17cases and at L5-S1 level in 13 cases. For all patients, a simple lumbosacral spine X-ray with dynamic films for preoperative and postoperative follow-up as well as an MRI of the lumbosacral spine were performed. The Visual Analogue Scale (VAS) and the Oswestry Disability Index (ODI) were used to measure the clinical and functional outcomes. The median follow up was 11 months.* ***Results:*** *At the OPAL cages one-year follow-up, satisfactory fusion was achieved at all levels. With our method of decompression, there were no dural tears or any intraoperative problems, and the fusion rate was 96.66% (29 patients). A follow-up with OPAL cages showed a higher fusion rate, improved realignment, and reduced resorption.* ***Conclusion:*** *With minimal side effects, TILF using OPAL cages and the expeduim screw system has produced better clinical outcomes and higher rates of circumferential fusion. OPAL cages stabilize spinal segments primarily by distracting them and facilitating bone fusion and ingrowth. They also help to distract the space between vertebral bodies, which facilitates spondylolisthesis correction.*

Keywords: *Spondylolisthesis, OPAL cage, TILF, Bone ingrowth, VAS, ODI.*

1. Introduction

Kilian originally defined spondylolisthesis as a gradually progressing dislocation of a lumbar vertebra in 1854. In the early stages of slipping, patients with spondylolisthesis may present with acute low back pain; in more rare cases, sciatica may result from pressure or traction on the nerve roots at the level of the defect, or there may be a bulging disc associated with the condition. Chronic low back pain is caused by ligamentous strain from instability at the level of the slip [1,2]. Wiltse categorized spondylolisthesis into six categories according to the cause: pathologic, congenital, traumatic, isthmic, degenerative, and iatrogenic. According to radiology, the Meyerding grading system assigns five grades to each slip. Grade I corresponds to values between 0% and 25%, grade II to values between 25% and 50%, grade III to values between 50% and 75%, grade IV to values between 75% and 100%, and grade V spondyloptosis to values more than 100% [3,4]. For the treatment of spondylolisthesis, several lumbar fusion techniques, with or without instrumentation, have been used. These techniques include anterior lumbar interbody fusion (ALIF), posterior lumbar fusion (PLF), circumferential 360 fusion (front

and back), and more recently TLIF [5-7]. The necessity of reducing the sagittal plane imbalance has persisted in controversy because of the elevated risk of damage to neural structures, particularly in cases of high-grade spondylolisthesis [8-11]. Due to the several fusion types that contribute to different efficacies, high-level evidence of the optimal surgical method is still lacking [12-16]. Since Harms and Jeszensky developed the TLIF treatment for spondylolisthesis [17], it has been possible to overcome PLIF, which is only effective at levels L3 to S1. This is because severe retraction on the thecal sac at higher levels increases the danger of neurological structural injury [18]. Furthermore, the contralateral facet joint and lamina can be preserved because TLIF only necessitates a unilateral approach [19]. Our hypothesis was that the TLIF technique, which restores the anatomic intradiscal height and tension of the annulus and ligamentous structures surrounding the disc spaces, is a safe and very effective surgical strategy for treating low-grade spondylolisthesis. This study aims to report the radiographic and clinical outcome of a consecutive series of low-grade spondylolisthesis patients selected for the surgery. *Compliance with ethical standards*: Prior to taking part in the trial, which was approved by the Institutional Ethics Committee, all patients provided written informed permission.

2. Patients and Methods

This is a retrospective review of a prospectively collected data for procedure for a consecutive series of selected patients of low-grade spondylolisthesis underwent TLIF procedure in the period between June 2018 to October 2022 at Aswan university Hospital. The study included thirty consecutive patients scheduled for TLIF who had symptomatic degenerative and isthmic spondylolisthesis. Ages 25 to 60 (average age of 36), low grade (Meyerding Grade-I and II) spondylolisthesis with or without adjacent level disc degeneration, radicular symptoms and or back pain that was consistent with radiologic findings were the inclusion criteria. This study excluded patients with prior spinal surgery, degenerative scoliosis or preoperative coronal imbalance, vascular claudication, diabetic neuropathy of limb, and chronic medication use, such as sedatives, opioids, and antidepressants (>6 months of use).

2.1. *Surgical technique*

Half an hour prior to the procedure, preoperative antibiotics were administered. The patient was made to lie prone on a spine frame, with the abdomen free and all bony areas carefully cushioned. Under general anaesthesia, the same senior spine surgeon performed all of the surgeries. Next, the surgical site was prepared and covered in the customary sterile manner. Prior to the incision, a time out was conducted. With the use of a C-arm picture, the proper level was located. The skin over the planned surgical levels was incised, and the subcutaneous tissue was dissected all the way down to the deep fascia level. A typical subperiosteal manner was used to expose the posterior parts. The transverse processes, bilateral facet joints, bilateral laminae, and spinous process were all dissected. Retractors that self-retained were positioned. To ensure that the spinal level was correct, an intraoperative radiograph was obtained. Expedium polyaxial Bilateral transpedicular screws were inserted. From the side of radicular symptoms, the TLIF treatment was carried out. The Mcdonald dissector was inserted beneath the top lamina until the dura was felt. Then, the lamina above the dissector was removed until the dura was seen. The ligamentum flavum was then removed to the lower lamina and decompressed until the neve root was seen. By using this procedure, we were able to avoid dural tears, fig. (1)

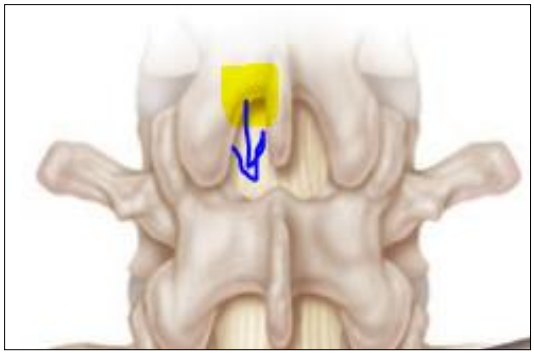

Figure (1) Anatomy of direction of decompression

After the dura and transverse roots were sufficiently liberated to allow for the dural retractor, the discectomy was carried out. The nucleus pulposus and the surface layers of the cartilaginous endplates were removed from the intervertebral discs using curettes, Shavers, and excision instruments of the OPAL system using a transforaminal approach. The vascularization of the bone transplant depends on the endplates being cleaned appropriately. However, by removing bone from beneath the cartilaginous layers, excessive cleaning can weaken the endplates. Loss of segmental stability and sinking may result from removing the complete endplate. To ascertain whether the height was appropriate, a sizer trial was conducted. Put the trial implant in place. Try to place the trial implant across the midline and 3-4 mm from the anterior longitudinal ligament by gently pressing on its end (diameter 10 mm to 12 mm, lengths 24 to 28 mm, width 10 mm). It is best to align the trial implant shaft 30 to 45 degrees from the midline. Once it has reached the desired depth Rotate the trial implant 90 degrees clockwise to distract and evaluate appropriate height by C-arm. Continue using the subsequent trial implant of a greater size until the desired anterior height is reached. During the insertion use fluoroscopy to confirm the trial implant positioning. Choose a cage based on the dimensions measured with the trial implant in the earlier stages. The cages were filled with bone harvested from the posterior elements and bone graft replacement paste. There was sufficient autograft bone produced from the posterior components packed into the disc space. Till the cage is positioned across the midline and 3-4 mm from the anterior longitudinal ligament, gently tap the end of the implant holder. The OPAL cage is lumbar interbody cage made from PEEK and contain two titanium alloy markers pins which allows for visualization of the implant (peek = polyetheretherketone). We used one cage in midline, use fluoroscopy to confirm position and fit of the implant, The implant must fit tightly to preserve the segmental height. On the side opposite the TLIF, decompression was accomplished. Using a Murphy probe, the decompression of the foramen was verified, and ultimately, bilateral confirmation of the decompression of the exiting and traversing nerve roots was obtained. For washing we used normal saline. After carefully decorating the transverse processes, the leftover bone from the posterior parts was employed as a posterolateral graft. After that, a lordotic expedium rod of the proper size was caught in the screws on both sides. C-arm was taken for the final check. After inserting the suction drain, the closer is completed in layers. For skin closure we used skin clips. Hospital stays averaged 4 days Postoperatively. On the first postoperative day following surgery, the patients were allowed to leave their beds under the supervision of a physiotherapist. They also began performing stretches on their piriformis and back muscles. Immediately following surgery as well as three, six, and twelve months later, radiography was done. Eleven men and nineteen women participated in the study. The majority of the patients had chronic low back pain, 23 had neurogenic intermittent claudication, and seven had sensorimotor dysfunction of the lower limbs. Magnetic Resonance Imaging (MRI) lumbosacral spine and plain X-ray lumbosacral spine radiographs, including anteroposterior, lateral, and dynamic flexion and extension views, were used to evaluate all patients radiologically. Twelve individuals had grade II spondylolisthesis and eighteen patients had grade I spondylolisthesis on preoperative lateral radiography. The lumbar spine's magnetic resonance imaging (MRI) revealed facet enlargement, ligamentum flavum hypertrophy, canal stenosis, and nerve root compression. 21 cases had degenerative spondylolisthesis and 9 patients had isthmic spondylolisthesis.

Thirteen patients had fusions performed at L5-S1, and seventeen at L4-L5. Due to lumbar canal stenosis and adjacent level disc disease, three patients underwent surgery on two levels and 27 patients underwent surgery on one level. Preoperative and postoperative assessments of the clinical outcomes were conducted using the Oswestry Disability Index (ODI) and Visual Analogue Scales (VAS) for back and leg pain. The absence of motion on flexion-extension radiography views, the absence of a dark hole surrounding a cage on anterior-posterior and lateral views, and the continuous presence of visible bone within each cage were used to determine the success of fusions. 11 months was the average follow-up period (range: 6 to 24 months). Excellent, good, fair, or poor were used to assess outcome. Satisfactory outcomes were considered with Excellent or Good; unsatisfactory outcomes were considered with fair or poor. Clinical improvement of pain and activity level, radiologically proven fusion, and active job status at the time of follow-up were used to assess the outcome.

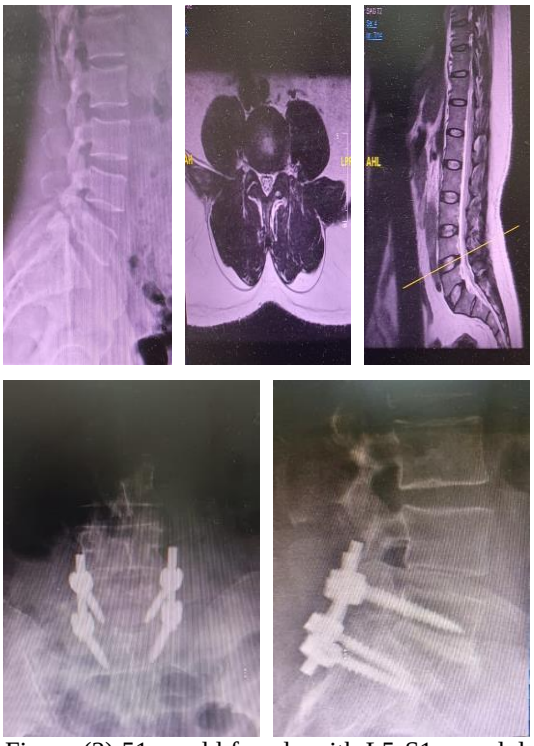

Figure (2) 51 ys old female with L5-S1 spondylolithesis (preoperative xray and MRI, postoperative xray)

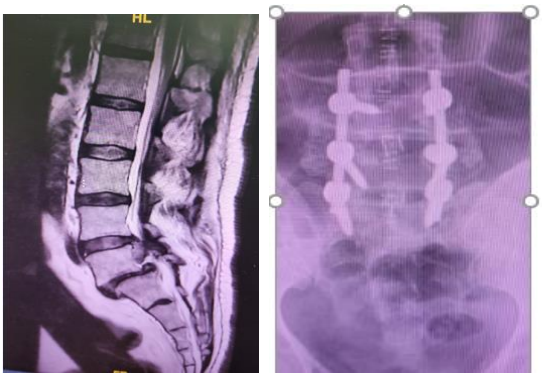

Figure (3) 46 ys male with L5-S1 spondylolitheis with L4-5 adjacent level disc disease and caudal disc migration (preoperative MRI and postoperative x-ray)

3. Results

This study includes thirty patients. L4-L5 was the operating segment for 17 patients (56.66%), while L5-S1 was the operative level for 13 patients (43.33%). With a mean of 36, the ages ranged from 25 to 60. 19 women and 11 men participated in the study. The symptoms persisted on average for 10.8 months (6-14 months). Eleven months was the average follow-up period (6 to 24 months). For all patients, the primary complaint was low back pain, neurological claudication, and/or discomfort radiating to the lower limbs. The physical results and clinical symptoms did not differ in males and females. According to Meyerding, the degree of anterior displacement was grade I in 18 patients (60%) and grade II in 12 patients (40%). Nine patients (30%) had isthmic spondylolisthesis, while 21 patients (70%) had degenerative spondylolisthesis. Patients with grade I or II spondylolisthesis had canal/foraminal stenosis on their MRIs, which may or may not have disc bulges. The average blood loss was 230 millilitres (between 160 and 300 millilitres), and the average operating time was 2.75 hours (between 2.5 and 3.5 hours). Transforaminal lumbar interbody fusion (TILF) was performed on all patients using OPAL peep cages and the EXPEDIUM 5.5 screws system. The cage sizes were 28 mm in length and 11 mm in height for 16 patients and 10 mm in length and 10 mm in height for 14 patients. Hospital stay

on average was 4 days (3to 5 days). There were no intraoperative complications. Physiotherapy with back, piriformis and hamstring muscles stretching exercise started from first postoperative day with a favorable response. According to an antibiotic culture sensitivity assessment, one patient had superficial wound infections that were successfully treated with oral antibiotics. The follow-up period lasted an average of 11 months (6-24 months). Preoperative mean VAS was 6.8, and postoperative mean VAS was 1.9. Preoperative mean ODI was 37.48, and the mean ODI scoring at the 12-month follow-up was 21.1. Ninety percent of patients who underwent surgery with OPAL cages expressed satisfaction with the outcome at their follow-up visit. Out of the 30 patients who underwent surgery, the fusion rate was 96.66 (of which 29 had satisfactory fusion on radiography, reducing postoperative VAS). There haven't been any significant intraoperative or postoperative problems in this study.

4. Discussion

Using Expedium 5.5 transpedicular screws and an OPAL cage, our study documented the clinical and radiological results of a TILF treatment for mild-grade spondylolisthesis (Meyerding grades I and II). Our experience with the TLIF treatment supports previous research findings, as it results in good to exceptional circumferential fusion rates and favourable clinical outcomes while avoiding anterior surgery problems such as retrograde ejaculation and damage to abdominal viscera or vascular systems. Furthermore, TLIF eliminates the requirement for severe dural retraction, which is necessary during PLIF and raises the risk of problems such dural laceration and neurapraxic damage. In terms of hospital stay and surgical data, our results are comparable to those of prior studies [20,21]. This study had a low risk of complications, Similar studies [21,22] also show that there were no intra-operative problems. According to a recent MRC study [23], up to 36% of perioperative complications occur. Although reports of transient neuritis as high as 7% have been made, our experience has not been that high. This is likely the result of excessive nerve root retraction. Anecdotal evidence suggests that the great arteries may suffer catastrophic vascular damage during cage insertion or decompression [24]. In ALIF, complications include retroperitoneal damage leading to dyspareunia in female patients, retrograde ejaculation in male patients, and great vascular injury (1.7%) with venous injury as high as 15.6% [24]. Because of these issues, TLIF is a more advantageous option to circumferential fusion. For years, there has been a contentious debate in the literature on the correlation between fusion rate and clinical result [25-28]. With a notable improvement in every grading system used, our patients' clinical outcomes—which included surgery for both degenerative and isthmic spondylolisthesis—can be considered good to excellent. Considering that our union rate was 96.66%, it is evident that the fusion rate and clinical outcomes are correlated. In our study, 11 (36.6%) of the patients were male, and 19 (63.3%) of the patients were female. It is demonstrated that the female gender predominates in degenerative spondylolisthesis [29]. In their research, Hackenberg documented the outcomes of TLIF with a minimum three-year follow-up [30]. They included individuals with disc degenerative disease in their study, who had TLIF in addition to those with low grade spondylolisthesis. However, similar to our study, they used ODI scoring as their tool and focused on the functional outcome. At the last follow-up, their mean ODI score was 31.6%, compared to 41.6% prior to surgery. The study conducted by Butterman G et al. revealed that three years following fusion surgery for spondylolisthesis, the mean ODI improved from 63% to 33% [31]. Our mean ODI was 37.48 preoperatively and 21.1 postoperatively, similar to these

studies. They had mainly patients with low-grade isthmic spondylolisthesis; Both degenerative and isthmic spondylolisthesis patients were included in our study. In comparison with them, our follow-up was short. Comparing postoperative scores at three and six months revealed statistically significant improvements in pain levels (VAS and ODI) and significant improvements in the SLR test. When comparing the outcomes from three and twelve months, there was a noticeable improvement. We think that the internal fixation device's stabilising action may be the cause of the initial symptom reduction, and that achieving a suitable fusion may be the cause of long-term symptom relief. In cases of mild grade spondylolisthesis, posterolateral fusion has been reported to have a fusion rate of 68%-100%. Our fusion rate was 96.66% using radiographic criteria for fusion assessment. It has been observed that augmenting fusion with pedicle screw fixation can speed up arthrodesis in cases of low grade spondylolisthesis [32], as well as to enhance clinical results [33]. However, McGuire and Amundson [34] did not discover any benefit to instrumentation. Furthermore, Kim et al. [35] found no extra advantages from instrumentation, their instrumented patient's fusion rate was lower than that of the uninstrumented group. Regarding the relationship between fusion and clinical result in the management of lumbar spinal diseases, there is conflicting evidence in the literature [36]. A prospective study found a direct correlation between an insufficiently successful arthrodesis and an unsatisfactory pain outcome [33]. According to some other research, an unsatisfactory outcome is directly correlated with the inability to obtain a successful arthrodesis [37]. However, while achieving a 90% fusion rate, Schnee et al. [36] only reported good clinical outcomes in 60% of patient They came to the conclusion that outcomes were considerably impacted by variables other than radiographic fusion and preoperative symptoms. Poor radiological fusion was shown to be linked in this study with poor clinical and functional result. When comparing the clinical and radiological fusion scores, it was shown that higher VAS pain levels were correlated with lower radiological fusion grades. At 12 months postoperatively, the mean ODI was 21.1 and the mean VAS scores were 1.9 in grade-I and grade-II fusions, respectively. This contrasts with the fusion grade IV (non-union) mean ODI of 36 and mean VAS score of 6. It is still difficult to objectively evaluate the clinical condition of non-traumatic lumbar diseases [38]. Because the VAS score and ODI are straightforward and have been utilised in a study comparing the outcomes of posterolateral fusion and transforaminal lumbar interbody fusion, we used them for our final evaluation of the results. Our results showed a 90% satisfactory outcome, which is comparable to the 60–98% reported in the literature [39,40]. However, due to variations in surgical techniques, bone graft types, equipment selection, postoperative immobilisation, rehabilitation, and smoking, a precise comparison of outcomes is challenging. According to our study's findings, solid fusion (96.66%) and an satisfactory clinical outcome (90%) are closely related. In most cases of low-grade isthmic spondylolisthesis, reducing the spondylolisthesis does not improve the situation [41]; Actually, when short-segment posterior stabilisation (in situ fusion and fixation) is utilised as the sole treatment, there is a demonstrable reduction [42]. Without attempting to reduce, Kim et al. [34] reported an overall 35% correction in anterior displacement. Our study showed an average correction of 10.9% for anterior displacement which was seen in the initial postoperative phase; however, no independent effort was taken to reduce the slide. Many advocates against reduction as the most controversial aspect of treating spondylolisthesis is slip reduction. They assert that the results of in situ fixing are good and comparable, with a minimal incidence of complications [43]. Still, some surgeons believe that leaving the basic pathology

unaddressed is against the basic principles [44]. An average reduction of 24% (grade-II) to 10% (grade-I) was attained by Pan J. and They said it happened spontaneously and was caused by circumferential release [32]. The average correction in our study was 10.9%, and the mean preoperative slip was 31.37% (grade-II) and postoperatively was 19.67% (grade-I). We believe that simple reduction can be achieved even with one-sided release and disc removal without raising the risk of complications. Distraction of a lumbar disc space has been thought to be clinically useful in easing neural compression because it increases the cross-sectional area of the neural foramen [45]. Although several publications have stressed the significance of restoring segmental lordosis and disc space height (DSH), there is a dearth of experimental evidence to support these ideas in clinical practice [34]. Excellent clinical outcomes with a considerable rise in DSH were demonstrated in our study. An explanation for this could be because the removal of segmental motion could prevent irritation of a nerve root, leading to an increase in the neural foramen's size and an improvement in symptoms. Because of the spontaneous restoration of lordosis at the unfused lumbar levels in lumbar spondylolisthesis, Cheng et al. showed that total LL (lumbar lordosis) improved following TLIF [46]. In their study, Jagannathan et al. discovered postoperatively elevated segmental and global LL. In our single level TLIF analysis, we also came to the same conclusion [47]. A comparable research group was not included in this study, and the data size was less. These are its drawbacks. Although theoretically we cannot effectively compare the results due to the short follow-up period, our analysis is reasonably comparable to the findings of previous studies. Confirmation of our findings will need to come from bigger patient numbers and longer follow-up in future prospective comparative trials (with other similar operations or with conservative care alone).

5. Conclusion

In order to accomplish circumferential fusion without experiencing severe problems, the Transforaminal Lumbar Interbody Fusion procedure, when combined with the Expedium 5.5 transpedicular screw system and OPAL cages, is a safe and very effective surgical approach for treating low grade spondylolisthesis. The results showed that the fusion rate was 96.66%, there was high postoperative clinical satisfaction, the local disc lordosis improved, the anatomic intradiscal height and tension of the annulus and ligamentous structures surrounding the disc spaces were restored, and early weight-bearing mobilisation was achieved.

References

[1] Fraser, R. (1995). Interbody, posterior and combined lumbar fusions. ***Spine***. 20 (24S): S167-S177.

[2] Elias, J., Simmons, N. & Kaptain, G. (2000). Complications of posterior lumbar interbody fusion when using a titanium cage device. ***J Neurosurg [Spine]***. 93: 45-52.

[3] Bradley, K. & Robert, D. (1998). Lumbar interbody cages. ***Spine***. 23: 634-640.

[4] Rapoff, A., Ghonayem, A. & Zdeblick, T. (1997). Biomechanical comparison of posterior lumbar interbody fusion cages. ***Spine***. 22: 2375-2379.

[5] Lee, C. & Kopacz, K. (2006). Lumbosacral: Posterior lumbar interbody fusion. In: Herkowitz, H., et al., (eds.) ***Rothman–Simeone The Spine***. Philadelphia: Elsevier: 350-360.

[6] Dickman, C. (1997). Internal fixation and fusion of the lumbar spine using threaded interbody cages. ***BNI Quarterly***. 13: 4-25.

[7] Kuslich, S., Ulstrom, C., Griffith, S., et al. (1998). The Bagby and Kuslich method of lumbar interbody fusion history, techniques and 2 year follow –up results of aunited states prospective, multicenter trial. ***Spine***. 23: 1267-1279.

[8] Kanyana, M., Cunningham B., Sefter, J., et al. (1999). Does spinal instrumentation influence healing process of posterolateral fusion? An in vivo animal model. ***Spine***. 24 (11): 1058-1065.

[9] Potter, B., Freedman, B., Verwiebe, E., et al. (2005). Transforaminal lumbar interbody fusion: clinical and radiographic results and complications in 100 consecutive patients. ***J Spinal Disord Tech***. 18: 337-346.

[10] Rosenberg, M. & Mummaneni, P. (2001). Transforaminal lumbar interbody fusion technique, complications and early results. ***Neurosurgery***. 48 (3): 569-574.

[11] Wilson-McDonald, J., Fairbank, J., Frost, H., (2008). Spine Stabil-ization Trial Group. The MRC spine stabilization trial: Surgical methods, outcomes, costs, and complications of surgical stabilization. ***Spine***. 33 (21): 2334-2340

[12] Gibson, J. & Waddell, G. (2005). Surgery for degenerative lumbar spondylosis: Updated cochrane review. ***Spine***. (Phila Pa 1976). 30: 2312-2320.

[13] Steiger, F., Becker, H., Standaert C., et al. (2014). Surgery in lumbar degenerative spondylolisthesis: Indications, outcomes and complications. A ***Syst Rev Eur Spine J***. 23: 945-973.

[14] Fallatah, S., Wai, E. & Baily C. (2013). The value of adding posterior interbody fusion in the surgical treatment of degenerative lumbar spine disorders: asystematic review. ***Int J Spine Surg***. 7:e 24-e28.

[15] Han, X., Zhu, Y., Cui, C., et al. (2009). A meta-analysis of circumferential fusion versus instrumented posterolateral fusion in the lumbar spine. ***Spine***. 34: E618-E625.

[16] Zhang, Q., Yuan, Z., Zhou, M., et al. (2014). A comparison of posterior lumbar interbody fusion and transforaminal lumbar interbody fusion: A literature review and meta-analysis. ***BMC Musculo Skelet Disord***. 15: 367.

[17] McCord, D., Cunningham, B., Shono, Y., et al. (1992). Biomechanical analysis of lumbosacral fixation. ***Spine***. 17 (suppl 8): S235-S243.

[18] Han, S., Hyun, S., Jahng, T., et al. (2015) Kim K.J. A comparative radiographic analysis of fusion rate between L4-5 and L5-S1 in a single level posterior lumbar interbody fusion. ***Korean J Spine***. 12(2): 60-67.

[19] Khan, N., Clark, A., Lee, S., et al. (2015). Surgical outcomes for minimally invasive vs open transforaminal lumbar interbody fusion: An updated systematic review and meta-analysis. ***Neurosurgery***. 77: 847-874

[20] Potter, B., Freedman, B., Verwiebe, E., et al. (2005). Transforaminal lumbar interbody fusion: clinical and radiographic results and complications in 100 consecutive patients. ***J. Spinal Disord Tech***. 18: 337-346.

[21] Rosenberg, M. & Mummaneni, P. (2001). Transforaminal lumbar interbody fusion technique, complications and early results. ***Neurosurgery***. 48 (3): 569-574.

[22] Salehi, S., Tawk, R., Ganju, A., et al. (2004). Transforaminal lumbar interbody fusion: surgical technique and results in 24 patients. ***Neurosurgery***. 54 (2): 368-374.

[23] Wilson-McDonald, J., Fairbank, J., Frost H., et al. (2008). The MRC spine stabilization trial: Surgical methods, outcomes, costs, and complications of surgical stabilization. ***Spine***. 33 (21): 2334-2340.

[24] Papadoulos, S., Konstantinou, D., Kourea, H., et al. (2002). Vascular injury complicating lumbar disc surgery. A systematic review. ***Eur J Vasc Endovasc Surg***. 24: 189-195.

[25] Zdeblick, T. (1993). A prospective randomized study of lumbar fusion: preliminary results. ***Spine***. 18 (8): 983-991.

[26] France, J., Norman, T., Santrock, R. et al. (1999). Randomised prospective study of posterolateral fusion: Outcome

with and without pedicle screw instrumentation. ***Spine***. 24 (6): 553-560.

[27] Kornblat, M., Casey, M. & Jacobs R. (1986). Internal fixation in lumbosacral spine fusion: a biomechanical and clinical study. ***Clin Orthop***. 203: 141-150.

[28] Fritzell, P., Hagg, O., Wessberg, P., et al. (2001). Swedish lumbar spine study group. 2001 Volvo award winner in clinical studies. Lumbar fusion vs non-surgical treatment for chronic low back pain: A multicentre randomized controlled trial from the Swedish Lumbar Spine Study Group. ***Spine***. 26 (23): 2521-2532.

[29] Sanderson, P. & Fraser, R. (1996). The influence of pregnancy on the development of degenerative spondylolisthesis***. J Bone Joint Surg Br***. 78-B: 951-954.

[30] Hackenberg, L., Halm, H. & Bullmann, V. (2005). Transforaminal lumbar interbody fusion: A safe tec-hnique with satisfactory three to five year results. ***Eur Spine J.*** 14: 551. doi: 10.1007/ s00586-004-0830-1.

[31] Buttermann, G., Garvey, T., Hunt, A., et al. (1998). Lumbar fusion results related to diagnosis. ***Spine (Phila Pa 1976***. 23: 116-127.

[32] Ricciardi, J., Pflueger, P. & Isaza, J. (1995). Transpedicular fixation for the treatment of isthmic spondylolisthesis in adults. ***Spine***. 20: 1917-1922.

[33] Kwon, B., Bilibrand, A. & Malloy, K. (2005). A critical analysis of the literature regarding surgical approach and outcome for adult low-grade isthmic spondylolisthesis. ***J Spinal Disord Tech.*** 18: 530-540.

[34] McGuire, R. & Amundson, G. (1993). The use of primary internal fixation in spondylolisthesis. ***Spine (Phila Pa 1976)***. 18: 1662-1672.

[35] Kim, N. & Lee, J. (1999). Anterior interbody fusion versus posterolateral with transpedicular fixation for isthmic spondylolisthesis in adults. A Comp Clin Results. ***Spine***. 24: 812-817.

[36] Schnee, C., Frcese, A. & Ansell L. (1997). Outcome analysis for adults with spondylolisthesis treated with posterolateral fusion and transpedicular screw fixation***. J Neurosurg***. 86: 56-63.

[37] El Masry, M., El Assuity, W. & El Hawary, Y. (2005). Instrumented insitu posterolateral fusion for low grade isthmic spondylolisthesis in adults. ***Acta Orthop Belg***. 71 (1): 83-87.

[38] Jacobs, W., Vreeling, A. & De Kleuver, M. (2006). Fusion for low - grade adult isthmic spondylolisthesis: A systemic review of the literature. ***Eur Spine J.*** 15 (4): 391-402.

[39] Wenger, M., Sapio, N. & Markwalder, T. (2005). Long-term outcome in 132 consecutive patients after posterior internal fixation and fusion for Grade I and II isthemic spondylolisthesis. ***J Neurosurg Spine***. 2: 289-297.

[40] Naderi S., Manisali M. & Acar, F. (2003). Factors affecting reduction in low grade instrumented spondylolisthesis. ***J Neurosurg***. 99: 151-156.

[41] Butt, M., Dhar, S., Hakeem, I., et al. (2008). In situ instrumented posterolateral fusion without decompression in symptomatic low-grade isthmic spondylolisthesis in adults. ***Int Orthop***. 32 (5): 663-669.

[42] Oh, C., Ji G., Jeon, J., et al. (2013). Slip reduction rate between minimal invasive and conventional unilateral transforaminal interbody fusion in patients with low-grade isthmic spondylolisthesis. ***Korean J Spin***e. 10 (4): 232-236.

[43] Pan, J., Lijun, L., Qian, L., et al. (2011). Spontaneous slip reduction of low-grade isthmic spondylolisthesis following circumferential release via bilateral minimally invasive transforaminal lumbar interbody fusion: Technical note and short-term outcome. ***Spine (Phila Pa 1976)***. 36 (4): 283-289.

[44] Chen, D., Fay, L., Lok J., et al.

(1995). Increasing neuroforaminal volume by anterior interbody distraction in degenerative lumbar spine. ***Spine***. 20: 74-79.

[45] Brantigan, J. & Neidre, A. (2003). Achievement of normal sagittal plane alignment using a wedged carbon fiber reinforced polymer fusion cage in treatment of spondylolisthesis. ***Spine J.*** 3: 186-196.

[46] Jagannathan, J., Sansur, C., Oskouian, R., et al. (2009). Radiographic restoration of lumbar alignment after transforaminal lumbar interbody fusion. ***Neurosurgery***. 64: 955-963.

[47] Ould-Slimane, M., Lenoir, T., Dauzac, C., et al. (2012). Influence of transforaminal lumbar interbody fusion procedures on spinal and pelvic parameters of sagittal balance. ***Eur Spine J.*** 21: 1200-1206.