ABSTRACT

Purpose: Expandable titanium transforaminal lumbar interbody fusion (TLIF) devices are a relatively new group of implants allowing restoration of lumbar lordosis (LL) and thus improvement of sagittal alignment. The purpose of our study is to compare clinical and radiological results of two different expandable TLIF devices.

Materials and Methods: In a retrospective study, patients who underwent TLIF surgery with a banana-shaped or straight TLIF cage in our spine center were analyzed. Primary outcome was change of disc height (DH), segmental lordosis angle (SLA), and lumbar lordotic angle (LLA). Moreover, basic patients parameters and cage subsidence were evaluated.

Results: Sixty-one patients were studied (33 banana-shaped and 28 straight cages). DH changed in the banana group from 4.8 mm (standard deviation SD 2.5) to 10.4 (SD 2.4) and in the straight cage group from 6.2 mm (SD 2.5) to 9.6 mm (SD 1.7). The difference was statistically significant \( P = 0.03 \). In addition, SLA correction was higher in the banana group with 5.8° (SD 5.0)–3.7° (SD 3.6), but not significant. LLA improved in the straight group with 5.2 (SD 6.4) compared to 3.7 (SD 5.8) in the banana group. We found subsidence in four patients (6.6%) in the banana-shaped group and nine cases (14.8%) in the other group.

Conclusions: Expandable titanium implants show similar improvements in restoring segmental and global lordosis. Banana-shaped expandable cages offer higher potency restoring the intervertebral DH and show less rates of subsidence compared to straight expandable cages.

Keywords: Banana-shaped, disc height, expandable transforaminal lumbar interbody fusion, global lordosis, segmental lordosis, straight, subsidence

INTRODUCTION

Transforaminal lumbar interbody fusion (TLIF) is an effective, well known, and often used procedure in degenerative disc disease.\(^1\) The aim of surgery is pain reduction and segmental fusion. In recent years, the importance of the sagittal alignment in spinal arthrodesis has been well demonstrated. Here, the correlation of a restored LL and improvement of the quality of life was shown by many authors.\(^1,2\) Most orthopedic- and neurosurgeons are familiar with a posterior approach to the spine and the advantage of TLIF to other posterior approaches like posterior lumbar interbody fusion (PLIF) is a reduced neural tissue retraction and a reduced trauma to bony structures.\(^3\) Restoring lordosis is possible through shortening the posterior column or lengthening the anterior column of the spine. The first TLIF implants were static and limited in balancing the sagittal lumbar alignment. Therefore, many studies were published which show satisfactory results with anterior LIF (ALIF)\(^4\) or lateral (oblique lateral interbody fusion,\(^5\) lateral lumbar

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interbody fusion,\(^6\) and extreme lateral lumbar interbody fusion\(^7\) applied implants in the lumbar spine. Expandable TLIF cages are a relatively new group of implants, which offer surgeons the possibility to affect greater lordosis than static devices by lengthening the anterior column and using a well-known posterior approach without the support of an access surgeon.\(^8\) Expandable TLIF implants give surgeons the opportunity to maximize the potential for restoring lordosis while minimizing the challenge of insertion through a parallel distraction in the intervertebral disc space and an optimized endplate to endplate fit.\(^9\) Common designs for expandable and static TLIF cages are a banana-shaped or straight design.\(^10\) While straight cages are inserted in an oblique position of the intervertebral disc space, banana-shaped implants are usually placed into a more anterior position. However, there are no published data which compare these two TLIF implant designs of expandable cages and their effect on the intervertebral disc space, the segmental and LL. In this study, we evaluated the clinical and radiological data to elucidate the influence of the two different implants on lordotic parameters in single- or two-level degenerated disc diseases. We hypothesized that banana-shaped expandable TLIF implants would result in greater lordosis correction than straight expandable implants due to a higher potential of lengthening the anterior column.

**MATERIALS AND METHODS**

In a retrospective cohort study, patients who underwent TLIF surgery due to a degenerative disc disease of lumbar spine at a single institution between 2015 and 2017 were analyzed.

We included patients undergoing a one-level or two-level TLIF surgery with an expandable device. A single surgeon performed surgery and patients were categorized according to cage type (banana-shaped vs. straight). Surgical technique was a standard TLIF approach with unilateral removing of the facet joint, direct decompression, endplate preparation, and oblique or anterior interbody cage insertion. Parallel and lordotic expandable cages were used, one cage design was straight with a position in the middle or the posterior third of the vertebral body [Figure 1], while the other cage was banana-shaped and placed as anterior as possible in the intervertebral disc space, preferably on the apophyseal ring [Figure 2].

Radiological evaluation was performed on pre- and post-operative plain radiographs of the lumbar spine. The segmental lordotic angle (SLA) was measured as the Cobb angle between lines parallel to the upper endplate of the cranial vertebra and the lower endplate of the caudal vertebra of the index level [Figure 3a]. The lumbar lordotic angle (LLA) was found as the Cobb angle between the lines parallel to superior endplate of L1 and the upper endplate of the sacrum [Figure 3b]. Disc height (DH) was defined as the distance between the center of the superior and inferior endplates of the index level [Figure 3c]. Cage subsidence was defined as >2 mm migration of the interbody cage into the adjacent vertebral bodies.

In addition, patient’s demographics including sex and age at time of surgery were collected. Furthermore, duration of intermediate care and hospitalization were recorded and compared as well as major complications.

Statistical analysis was performed using Students t-test. The test was used to compare the perioperative and radiological parameters between the two groups of expandable cages. Statistical significance was defined as \(P < 0.5\). All analysis were conducted using IBM SPSS version 23 (IBM Corporation, Armon, NY, USA).

**RESULTS**

We identified 61 patients who underwent expandable TLIF surgery with cage placement in our hospital. In 33 cases,
a banana-shaped implant and in 28 cases a straight TLIF cage was applied. Baseline characteristics were similar in the groups [Table 1]. In the banana-shaped group, the mean Operative time (OR) was shorter than in the straight group with (134.1 [standard deviation [SD] 39.0]–142.5 [SD 40.0] min). However, the difference was not statistically significant ($P = 0.49$). There was also no significant difference between the hospital stay (9.1 [SD 6.5] days in the banana vs. 11.6 [SD 6.6] days in the straight group) corresponding to $P = 0.15$. On average, the intervertebral DH in the straight group was 6.2 mm (SD 2.5) before cage implantation and increased up to 9.6 mm (SD 1.7) postoperative.

In the banana-shaped group [Figure 4], different results were found. Here, the intervertebral DH changed from 4.8 mm (SD 2.5) preoperative to 10.4 mm (SD 2.4) postoperative. The change was 5.6 mm (SD 2.9) in the banana-shaped group and 3.4 mm (SD 2.6) in the straight group. A t-test showed a statistic relevant difference with a $P = 0.03$ between the groups [Table 1 and Figure 5]. There was also a change in the segmental lordosis (SL). In the banana-shaped group, the Cobb angle changed from 19.6° (SD 8.9) to 25.9° (SD 9.2) postoperative. In the straight group, the angle increased from 18.5° (SD 7.7) to 22.9° (SD 8.6). We found no significant differences in SLA changes ($P = 0.69$) but a higher correction in the banana group [Figure 5].

Subsidence was found overall in 13 cases (21.3%). 9 cases (14.8%) were in the straight group and only 4 cases of subsidence (6.6%) occurred in the banana-shaped group. We found no statistic difference between the two groups ($P = 0.58$) [Table 1]. At least, we evaluated the LL between the endplates of L1 and S1. We found a better correction in the straight group. Before surgery, the LLA was 38.0° (SD 9.0)
and increased 5.2° (SD 6.4) to 44.1° (SD 6.4). In the banana group, the change was 3.7° (SD 5.8). Here, the angle changed from 40.7° (SD 15.9) to 44.4° (SD 13.7). A statistical analysis showed no significance ($P = 0.32$).

**DISCUSSION**

To the best of our knowledge, this is the first study to compare two different expandable TLIF devices. The DH in the group of the banana-shaped cages improved from 4.8 mm preoperative to 10.4 mm postoperative. In the other group, it increased from 6.2 mm (SD 2.5) to 9.6 mm (SD 1.7). This improvement was statistically significant. Rice et al. compared static TLIF cages in a kidney (banana) and a straight-shaped design. The authors found a better lordosis correction in the group for the kidney-shaped implant in concordance to our results. We hypothesize that the reason for this phenomenon is the higher potency of a more anterior position of the implant compared to the oblique technique. The mean correction of the DH in the study of Rice et al. was also significantly better in the kidney group than in the straight group. This is similar to our results, although the authors did not compare expandable devices. In another study, Recnik et al. found an increase of DH after application of a static TLIF implant, but the authors did not notice any significant changes of the SL. Kwon et al. made a radiological analysis of TLIF in the treatment of isthmic spondylolisthesis and found in 35 patients an increase of DH and a higher restoration of lordosis when the static implant was placed as anterior as possible in the intervertebral disc space and concluded that the improvement in sagittal alignment is dependent on anterior placement of the interbody device. In contrast to our study, the authors did not compare different TLIF implants.

Gödde et al. published another clinical study about the influence of cage geometry on sagittal alignment. They included 42 patients who underwent short-segment posterior fusion and found out that wedge-shaped cages show better radiological results than rectangular cages. However, in this study, no expandable devices were used. Kim et al. published first results of minimally invasive (MIS) TLIF implants with the possibility to expand the device in the intervertebral space in 2016. They included 50 patients and used an expandable TLIF spacer. They found a preoperative DH of 8.3 mm, which increased postoperatively to 12.4 mm. The cage design was straight. This is comparable to our results, especially the change of the DH when using straight expandable cages. We detected an improvement of 3.4 mm but a higher correction in the more anterior placed banana-shaped TLIF. Another interesting fact is that they found no cage migration or subsidence in a 2-year follow-up.

Satisfactory clinical and radiological results when using expandable TLIF devices were published by Boktor et al. But as a difference to our data, the authors of that study included all types of cage design and different material properties and focused on clinical outcomes. Massie et al. looked at the results of an expandable banana-shaped implant in spondylolisthesis and found an increased DH of 3.1-mm postoperative, while we found 5.6 mm in our data with the same implant designs and material. Hawasi et al. found better restoration of DH with expandable MIS TLIF devices in comparison to static TLIF implants especially in patients with a collapsed disc.

But what is the effect of different TLIF designs on the sagittal alignment and the SL? Kim et al. found only small changes and increasing segmental Cobb angle from 9.1° to 10.3°. As mentioned before, in this study, a straight cage was used. In our data, the segmental Cobb angle was preoperative 18.5° (SD 7.7) and increased to 22.9° (SD 8.8) postoperative. We measured an improvement of 3.7°, whereas Kim et al. only 1.2° with the same implant design. A difference can be found in the surgical approach, because we included open and MIS approaches, while in the cited study only MIS was used. Choi et al. published a prospective randomized clinical trial. They applied banana-shaped and straight cages in MIS TIF and enrolled 40 patients. The authors found a significant greater change of DH and SL in the banana-shaped group. Moreover, they found more subsidence rates in the banana-shaped group. In our data, we measured preoperatively a SLA of 19.6° (SD 8.9) in the banana group. This angle increased postoperatively to 25.9° (SD 9.2). The change was 5.8° (SD 5.0) and therefore higher than in the published studies as a result of the cage design and the implant distraction. Yee et al. published different results. The investigators compared segmental and lumbar sagittal angles of expandable and static cages in TLIF and found no significant differences between the groups and lower correction values than we did. Therefore, the authors concluded that an expandable device alone do not consistently achieve greater increases in lumbar and SL. Studies evaluating the effect of expandable cages on lordosis in TLIF are rare. A cadaveric study was published by Qandah et al.; they performed Smith–Peterson osteotomies on human cadaveric spines and documented the effect of expandable TLIF on sagittal balance. The authors found that each additional millimeter in height expansion resulted in a 1° correction of LL. Subsidence was found in 9 of 21 interbody levels because of poor bone quality. Alimi et al. studied 49 patients with polyetheretherketone implants who underwent TLIF surgery and found no significant changes in SL and LL. Our data showed improvement of LL for both groups. In the banana-shaped group, we saw...
preoperative a Cobb angle of 40.7° (SD 15.9°) which changed to 44.4° (SD 13.7) postoperative. Even higher changes with 5.2° (SD 6.4) were measured in the group of the straight cages. Here, the lordosis between L1 and S1 increased from 38.0° (SD 9.0) to 44.1 (SD 9.1). Our data show better results than in comparable literature.\cite{17,18} Ahlquist et al. compared different approaches and found that ALIF and LLIF produced greater improvement in radiographic measurements in comparison to TLIF and PLIF. The authors examined expandable and static devices in their data. This was different to our study design.\cite{21} Jäger and Tassemeier used expandable devices to restore the sagittal alignment in osteoporotic bone in a TLIF technique and showed in a case report the opportunity to lengthen the anterior column of the spine with a posterior placed device.\cite{22} Cage subsidence is well known in the history of interbody devices and can lead to a loss of DH and lordosis.\cite{23-25} Choi et al. found subsidence rates of 33.3% after TLIF surgery at L5-S1.\cite{26} We saw subsidence of cages in 4 cases (6.6%) of the banana-shaped group and in 9 patients (14.8%) of the straight group. There was no need to perform revision surgery. On the other hand, Kim et al. found no subsidence in fifty patients.\cite{15} Reasons for that could be a different technique of disc preparation. Excessive and overzealous curettage can lead to endplate damage and cage subsidence and surgeons have different standards for sufficient endplate curettage.\cite{27} Other factors that may affect subsidence rates are patient-related like osteoporosis and obesity.\cite{28}

**CONCLUSIONS**

In this clinical trial, we compared the radiological and clinical outcomes of expandable titanium TLIF performed using banana-shaped and straight cages. To the best of our knowledge, there are no published data comparing different cage designs of the expandable technique. The banana cage was significantly superior to the straight cage in terms of restoring DH and showed less rates of subsidence and a better SL correction. The straight cage was superior in restoring the LL but without statistical significance.

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**Conflicts of interest**

There are no conflicts of interest.

**REFERENCES**

1. Kono Y, Gen H, Sakuma Y, Koshika Y. Comparison of clinical and radiologic results of mini-open transforaminal lumbar interbody fusion and extreme lateral interbody fusion indirect decompression for degenerative lumbar spondylolisthesis. Asian Spine J 2018;12:356-64.
2. Chang HS. Influence of lumbar lordosis on the outcome of decompression surgery for lumbar canal stenosis. World Neurosurg 2018;109:e684-90.
3. Xue DS, Walker CT, Godzik J, Turner JD, Smith W, Uribe JS, et al. Minimally invasive anterior, lateral, and oblique lumbar interbody fusion: A literature review. Ann Transl Med 2018;6:104.
4. Kleiney JP, Cheng I, Alamin TF, Hu SS, Cha T, Yanamadala V, et al. Selective anterior lumbar interbody fusion for low back pain associated with degenerative disc disease versus nonsurgical management. Spine (Phila Pa 1976). 2018 Mar 9. doi: 10.1097/BRS.0000000000002630. [Epub ahead of print].
5. Jin C, Jaiswal MS, Jeon SS, Ryu KS, Hur JW, Kim JS, et al. Outcomes of oblique lateral interbody fusion for degenerative lumbar disease in patients under or over 65 years of age. J Orthop Surg Res 2018;13:38.
6. Miscusi M, Ramieri A, Forcato S, Giuffrè M, Trungu S, Cimatti M, et al. Comparison of pure lateral and oblique lateral inter-body fusion for treatment of lumbar degenerative disk disease: A multicentric cohort study. Eur Spine J 2018;27:222-28.
7. Goyal A, Kereczoudis P, Alvi MA, Goncalves S, Bydon M. Outcomes following minimally invasive lateral transspinosus interbody fusion for degenerative low grade lumbar spondylolisthesis: A systematic review. Clin Neurol Neurosurg 2018;167:122-8.
8. Boktor JG, Pockett RD, Verghese N. The expandable transforaminal lumbar interbody fusion – Two years follow-up. J Craniocervtal Junction Spine 2018;9:50-5.
9. Massie LW, Zakaria HM, Schultz LR, Basheer A, Durst A, Chang V, et al. Assessment of radiographic and clinical outcomes of an articulating expandable interbody cage in minimally invasive transforaminal lumbar interbody fusion for spondylolisthesis. Neurosurg Focus 2018;44:E8.
10. Yang B, Ou Y, Jiang D, Wang X, Yang D. Biomechanical study on kidney-shaped nano-hydroxyapatite/polyamide 66 cage. Zhongguo Xiu Fu Chong Jian Wai Ke Za Zhi 2015;29:746-50.
11. Rice JW, Sedney CL, Daffner SD, Amer JW, Emery SE, France JC, et al. Improvement of segmental lordosis in transforaminal lumbar interbody fusion: A Comparison of two techniques. Global Spine J 2016;6:229-33.
12. Recnik G, Kosak R, Venguš R. Influencing segmental balance in isthmic spondylolisthesis using transforaminal lumbar interbody fusion. J Spinal Disord Tech 2013;26:246-51.
13. Kwon BK, Berta S, Daffner SD, Vaccaro AR, Hilibrand AS, Grauer JN, et al. Radiographic analysis of transforaminal lumbar interbody fusion for the treatment of adult isthmic spondylolisthesis. J Spinal Disord Tech 2003;16:469-76.
14. Gödde S, Fritsch E, Dienst M, Kohn D. Influence of cage geometry on sagittal alignment in instrumented posterior lumbar interbody fusion. Spine (Phila Pa 1976). 2003;28:1693-9.
15. Kim CW, Doerr TM, Luna IY, Joshua G, Shen SR, Fu X, et al. Minimally invasive transforaminal lumbar interbody fusion using expandable technology: A clinical and radiographic analysis of 50 patients. World Neurosurg 2016;90:228-35.
16. Hawasli AH, Khalifeh JM, Chatrath A, Yarbrough CK, Ray WZ. Minimally invasive transforaminal lumbar interbody fusion with expandable versus static interbody devices: Radiographic assessment of sagittal segmental and pelvic parameters. Neurosurg Focus 2017;43:E10.
17. Choi WS, Kim JS, Hur JW, Seong JH. Minimally invasive transforaminal lumbar interbody fusion using banana-shaped and straight cages: Radiological and clinical results from a prospective randomized clinical trial. Neurosurgery 2018;82:289-98.
18. Yee TJ, Joseph JR, Terman SW, Park P. Expandable vs. static cages in transforaminal lumbar interbody fusion: Radiographic comparison of segmental and lumbar sagittal angles. Neurosurgery 2017;81:69-74.
19. Qandah NA, Klocke NF, Synkowski JJ, Chinthakunta SR, Hussain MM, Salloum KG, et al. Additional sagittal correction can be obtained when using an expandable titanium interbody device in lumbar smith-peterson osteotomies: A biomechanical study. Spine J 2015;15:506-13.
20. Alimi M, Shin B, Macielak M, Hofstetter CP, Njoku I Jr, Tsions AJ, et al. Expandable polyaryl-ether-ether-ketone spacers for interbody distraction in the lumbar spine. Global Spine J 2015;5:169-78.

21. Ahlquist S, Park HY, Gatto J, Shamie AN, Park DY. Does approach matter? A comparative radiographic analysis of spinopelvic parameters in single-level lumbar fusion. Spine J 2018, pii: S1529-9430(18)30125-6.

22. Jäger M, Tassemeier T. The double-transforaminal lumbar interbody fusion: An innovative one-stage surgical technique for posterior kyphosis correction. Orthop Rev (Pavia) 2017;9:7107.

23. Zhao FD, Yang W, Shan Z, Wang J, Chen HX, Hong ZH, et al. Cage migration after transforaminal lumbar interbody fusion and factors related to it. Orthop Surg 2012;4:227-32.

24. Chen L, Yang H, Tang T. Cage migration in spondylolisthesis treated with posterior lumbar interbody fusion using BAK cages. Spine (Phila Pa 1976) 2005;30:2171-5.

25. Choi JY, Sung KH. Subsidence after anterior lumbar interbody fusion using paired stand-alone rectangular cages. Eur Spine J 2006;15:16-22.

26. Choi WS, Kim JS, Ryu KS, Hur JW, Seong JH. Minimally invasive transforaminal lumbar interbody fusion at L5-S1 through a unilateral approach: Technical feasibility and outcomes. Biomed Res Int 2016;2016:2518394.

27. Bagby G. The Bagby and Kuslich (BAK) method of lumbar interbody fusion. Spine (Phila Pa 1976) 1999;24:1857.

28. Lim TH, Kwon H, Jeon CH, Kim JG, Sokolowski M, Natarajan R, et al. Effect of endplate conditions and bone mineral density on the compressive strength of the graft-endplate interface in anterior cervical spine fusion. Spine (Phila Pa 1976) 2001;26:951-6.