Review Article

Interbody options in lumbar fusion

Dil V. Patel, Joon S. Yoo, Sailee S. Karmarkar, Eric H. Lamoutte, Kern Singh

Department of Orthopaedic Surgery, Rush University Medical Center, Chicago, IL, USA

Contributions: (I) Conception and design: DV Patel, JS Yoo, K Singh; (II) Administrative support: SS Karmarkar, EH Lamoutte; (III) Provision of study materials or patients: SS Karmarkar, EH Lamoutte; (IV) Collection and assembly of data: DV Patel, JS Yoo, SS Karmarkar, EH Lamoutte; (V) Data analysis and interpretation: DV Patel, JS Yoo; (VI) Manuscript writing: All authors; (VII) Final approval of manuscript: All authors.

Correspondence to: Kern Singh, MD. Professor, Department of Orthopaedic Surgery, Rush University Medical Center, 1611 W. Harrison St, Suite #300, Chicago, IL 60612, USA. Email: kern.singh@rushortho.com.

Abstract: Interbody devices have revolutionized lumbar fusion surgery by enhancing mechanical stability, optimizing sagittal parameters, and maximizing fusion potential. There are several lumbar interbody fusion approaches available for varying pathologic etiologies, surgical index levels, or due to surgeon preference. With the advancement of spinal instrumentation and interbody devices, a variety of cage materials and dimensions have been engineered to accommodate various lumbar fusion approaches. The efficacy of a fusion is dependent on the shape, size, and material makeup of that interbody device. Since there are numerous cages available in today's market, it is important to find the optimal cage to best accommodate specific lumbar fusion cases. This review will explain the properties and future advancements of various interbody devices available for lumbar fusions.

Keywords: Interbody devices; lumbar fusion; bone grafts; osteobiologics

Submitted Dec 03, 2018. Accepted for publication Apr 15, 2019.
doi: 10.21037/jss.2019.04.04
View this article at: http://dx.doi.org/10.21037/jss.2019.04.04

Introduction

Since 1911, lumbar fusion has proven to have excellent clinical outcomes in treating several pathological spine conditions, such as spinal stenosis, spondylolisthesis, recurrent herniated nucleus pulposus, degenerative disc disease, spinal deformity, and trauma (1,2) .The first lumbar fusions were achieved using tibial bone graft and wiring techniques, which then evolved to posterolateral fixation techniques including facet screws followed by more advanced pedicle screws and rods. In 1988, the first "load sharing" fusion took place with the use of an interbody device with supplemental posterolateral fixation (1). Since their introduction, interbody devices have revolutionized lumbar fusion surgery by enhancing mechanical stability, optimizing sagittal parameters, and maximizing fusion potential.

There are several lumbar interbody fusion approaches available for varying pathologic etiologies, surgical index levels, or due to surgeon preference. Successful interbody fusion not only results in restoration of lordosis and correction of deformity, but allows for decompression of neural elements both directly and indirectly depending on the approach (3,4). The common surgical approaches for lumbar interbody fusion include posterior lumbar interbody fusion (PLIF), transforaminal lumbar interbody fusion (TLIF), lateral lumbar interbody fusion (LLIF), oblique lumbar interbody fusion/anterior to psoas (OLIF/ATP), and anterior lumbar interbody fusion (ALIF) (3,4). The anterior and lateral approaches grant surgeons with a direct midline or lateral view of the disc space, which ultimately allows for a more thorough endplate preparation and maximization of implant size (3-6). Conversely, the posterior approaches provide excellent visualization of the nerve roots and spinal canal for direct decompression, however, they have a narrow surgical corridor which requires interbody devices with a smaller footprint (3-5).

With the advancement of spinal instrumentation and interbody devices, a variety of cage materials and dimensions have been engineered to accommodate various

© Journal of Spine Surgery. All rights reserved.

MEDTRONIC EXHIBIT 1022

lumbar fusion approaches. The efficacy of a fusion is dependent on the shape, size, and material makeup of that interbody device. Since there are numerous cages available in today's market, it is important to find the optimal cage to best accommodate specific lumbar fusion cases. As such, this review will explain the properties of various interbody devices available for lumbar fusions.

Fundamentals of interbody fusion

The main objective of interbody fusion is to distract the intervertebral space enough to implant a cage that will stabilize adjacent vertebral bodies until complete fusion occurs. The stretching of the annulus and supporting ligaments provides optimal stability and maintenance of proper disc height and lordosis (7). In general, interbody devices consist of a hollow center, which may be filled with bone grafts and other osteobiologics for fusion enhancement. Additionally, some cages have porous structure which increases osteoconductive properties (8). The time for fusion varies, but is 6–12 months at minimum, therefore immediate stabilization is required (9,10). As such, posterolateral pedicle screws and rods are required for most cages for maintenance of spinal stability until fusion occurs. However, some interbody devices used during anterior and lateral approaches may be combined with plate fixation or contain integrated screws or wedges that allow for immediate stabilization and avoid the need for patient repositioning for pedicle screw and rod placement (9,10). Although the basic concept of interbody cages remains the same, the design may vary in terms of material, shape, size, and whether it has static or expandable dimensions.

Interbody device materials

Interbody devices are mainly made of titanium alloys, polyetheretherketone (PEEK), or from biologic sources (11,12). The ideal interbody device is one that is rigid enough to maintain stability, but with a similar elastic modulus of bone to prevent subsidence and stress-shielding. Additionally, osteoconductive properties vary by material and other factors such as radiolucency allow for convenience during fusion assessments (11).

Traditionally, interbody devices have been made from metals such as titanium alloys due to their durability and strength (12). The benefits of titanium cages are their biocompatibility and resistance to corrosion. Moreover, they are associated with the highest osteoconductive potential, leading to the optimum fusion rates (13,14). However, titanium cages have a relatively high modulus of elasticity compared to bone, which often results in endplate trauma and subsidence (15,16). Additionally, titanium implants cause a distortion on magnetic resonance imaging (MRI) and computer tomography (CT) (12,17,18).

Interbody devices are also made from PEEK, which has an elastic modulus comparable to bone, allowing for relatively lower subsidence rates (16,19,20). Unlike titanium cages which are biocompatible, PEEK cages have a hydrophobic surface and therefore may limit osseointegration (19,21,22). Additionally, need for greater endplate preparation and problems with overdistraction compromise the effectiveness of PEEK cages (19,23). A major advantage of PEEK implants, however, is their radiolucent properties, which allow for better fusion assessment on imaging (19). For purposes of identification, these radiolucent cages often have metallic markers. Despite these differences, fusion rates between PEEK cages are comparable to titanium cages (24).

In order to procure the benefits of both materials, some devices have a hybrid cage design comprising of a PEEK body with titanium articulating edges. This combines the advantageous elastic modulus and radiolucent properties of PEEK with the biocompatibility and durability of titanium (25,26). Ultimately, this novel combination may potentially reduce stress-shielding and subsidence associated with titanium cages, while maintaining similar fusion rates to either titanium or PEEK materials (25,26). As hybrid implants grow in popularity, future studies may potentially reveal their efficacy.

Biologic implants are allogenic bone grafts derived from cadaveric specimen, which include femoral rings or cortical bone dowels (27). Femoral ring grafts have ridges that enhance their grips onto vertebral bodies and may be packed with autograft before interbody placement. In relation, threaded cortical bone dowels derived from the femur or tibia may be stand-alone options used in lieu of traditional cages. These biologic implants offer similar elastic modulus to bone with radiolucent properties for better fusion assessments (28). Disadvantages of biologic implants are the potential risk for fracture upon insertion (29).

Dimension of interbody devices

The cage shape also varies in terms of surgical approach and must allow for optimal positioning between adjacent vertebral endplates in order to enhance fusion (30). Varying

© Journal of Spine Surgery. All rights reserved.

shapes of cages include cylindrical, threaded, mesh, trapezoidal, rectangular, or banana-shaped.

The first-generation interbody devices were cylindrical titanium cages with a threaded body which could be screwed into position in either anterior or posterior approaches. However, their thick, titanium walls produce severe artifacts on MRI or CT (31). In relation, the second-generation cages maintained a threaded configuration, but had thinner walls which reduced imaging artifacts (31). A threaded design has advantages such as a quicker fusion time and immediate stability, however, it also has decreased maximum distractive height, is less stable in flexion and extension, and is associated with higher rates of subsidence compared to other designs (31,32). Titanium mesh cages have an open configuration for housing bone graft. The unique structural design of the mesh cages offers enhanced load sharing (30,33). Trapezoidal cages, made of either titanium or PEEK, are commonly used during ALIF procedures (34,35). The wide design and tapered shape maximizes surface area for fusion and restores sagittal alignment (34,35). Rectangular cages are designed for posterior and lateral approaches and are typically made of PEEK or PEEK reinforced with carbon-fiber. The greatest disadvantage of rectangular cages includes segmental kyphosis due to their long, flat profiles (36,37). Lastly, banana-shaped cages have a biconvex surface and are mostly reserved for transforaminal approaches. These devices have a large opening for graft insertion and transverse placement within the disc space allows for greater stability (37). However, since banana-shaped cages are positioned more medial and posterior, they may be associated with higher rates of subsidence when compared to straight-shaped cages (38).

An optimized fit for an interbody device depends on factors such as surgical approach, index level of procedure, and intervertebral anatomy (39). A larger footprint will enhance segmental stability and will equalize the stress distribution along the vertebral endplate (28,39). Cages too large increase the chance of damage to surrounding structures and nerve roots, but ones that are too small may lead to instability (28). Since disc height changes depending on the individual and index level, there are several height options available (28). It is important to choose a cage height that maintains disc space and lordosis. Overdistraction may cause endplate trauma and increase risk of adjacent segment disease, while cages that are too thin may lead to cage migration and fusion failure (2). Lastly, interbody devices may also come in varying angles for meeting specific sagittal parameter goals (28). Thus, surgeons should carefully select appropriate interbody dimensions on a case by case basis (2).

Static versus expandable interbody devices

Anterior approaches often have higher intervertebral exposure when compared to posterior approaches. Therefore, a wider implant is suitable for anterior fusion procedures (40,41). The size is limited in posterior and transforaminal approaches due to a smaller surgical corridor. However, advancements in spinal instrumentation technology have overcome this limitation through the development of expandable cages, which allow for *in situ* expansion within the disc space (40). Expandable cages may be deployed within the plane of the intervertebral space to provide a larger footprint or be mechanically distracted to increase height and lordotic angle (40,42). Controlled expansion prevents iatrogenic endplate damage during the procedure, most commonly from trialing and impaction seen with static devices (42). Despite these added features, current literature demonstrates that both static and expandable cages are associated with similar improvements in sagittal parameters and fusion outcomes (42,43).

Bone grafts and osteobiologics

The center of an interbody device is hollow and is often filled with bone grafts to enhance fusion. These bone grafts can be autogenic, allogenic, or synthetic. Autogenous bone grafts may be either derived locally from morselizing extracted bony elements during decompression or harvested from the iliac crest. Iliac crest bone graft (ICBG) has traditionally been the preferred graft material to enhance fusion, however, it has been associated with donor site morbidity and is limited in supply (14,44,45). Recent advances have given rise to alternatives, such as allograft or synthetic grafts and bone morphogenetic protein-2 (BMP-2), which have grown in popularity for lumbar fusion procedures (46,47). Demineralized bone matrix (DBM) is allograft cortical bone with the calcium and phosphate removed via an extraction process (48,49). DMB comes in a powder form that is mixed with a putty or paste carrier for use as a graft extender. In relation, ceramics are composed of calcium phosphate substrates that emulate the physical properties of bone. When used together with BMP-2, these alternative options allow for shorter operation times and avoid donor site morbidity compared to ICBG harvesting (13,50,51). However, there is no significant difference in fusion and clinical outcomes

© Journal of Spine Surgery. All rights reserved.

between ICBG and BMP-2 (18,52).

Conclusions

This in-depth review covers the properties of interbody devices and demonstrates that a variety of interbody devices can be utilized in each type of lumbar fusion procedure. Surgeons should thoroughly examine the characteristics associated with each device and determine their selection based on type of procedure, availability, price, and their experience with the device. Interbody device technology has demonstrated promising advances in spine surgery. Future advancements in design will hopefully lead to the reduction of subsidence and stress-shielding, while increasing arthrodesis rates and overall clinical outcomes.

Acknowledgments

None.

Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

References

1. de Kunder SL, Rijkers K, Caelers I, et al. Lumbar Interbody Fusion: A Historical Overview and a Future Perspective. Spine (Phila Pa 1976) 2018;43:1161-8.
2. Wang H, Chen W, Jiang J, et al. Analysis of the correlative factors in the selection of interbody fusion cage height in transforaminal lumbar interbody fusion. BMC Musculoskelet Disord 2016;17:9.
3. Mobbs RJ, Phan K, Malham G, et al. Lumbar interbody fusion: techniques, indications and comparison of interbody fusion options including PLIF, TLIF, MI-TLIF, OLIF/ATP, LLIF and ALIF. J Spine Surg 2015;1:2-18.
4. Xu DS, Walker CT, Godzik J, et al. Minimally invasive anterior, lateral, and oblique lumbar interbody fusion: a literature review. Ann Transl Med 2018;6:104.
5. Attenello J, Chang C, Lee YP, et al. Comparison of lateral lumbar interbody fusion (LLIF) with open versus percutaneous screw fixation for adult degenerative scoliosis. J Orthop 2018;15:486-9.
6. Kono Y, Gen H, Sakuma Y, et al. 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.
7. Burkus JK. Intervertebral fixation: clinical results with anterior cages. Orthop Clin North Am 2002;33:349-57.
8. Jain S, Eltorai AE, Ruttiman R, et al. Advances in Spinal Interbody Cages. Orthop Surg 2016;8:278-84.
9. Burkus JK, Heim SE, Gornet MF, et al. Is INFUSE bone graft superior to autograft bone? An integrated analysis of clinical trials using the LT-CAGE lumbar tapered fusion device. J Spinal Disord Tech 2003;16:113-22.
10. Rodgers WB, Gerber EJ, Patterson JR. Fusion after minimally disruptive anterior lumbar interbody fusion: Analysis of extreme lateral interbody fusion by computed tomography. SAS J 2010;4:63-6.
11. Kienle A, Krieger A, Willems K, et al. Resistance of coated polyetheretherketone lumbar interbody fusion cages against abrasion under simulated impaction into the disc space. J Appl Biomater Funct Mater 2019;17:2280800018782854.
12. Palm WJ, Rosenberg WS, Keaveny TM. Load transfer mechanisms in cylindrical interbody cage constructs. Spine (Phila Pa 1976) 2002;27:2101-7.
13. Mobbs RJ, Chung M, Rao PJ. Bone graft substitutes for anterior lumbar interbody fusion. Orthop Surg 2013;5:77-85.
14. Mobbs RJ, Coughlan M, Thompson R, et al. The utility of 3D printing for surgical planning and patient-specific implant design for complex spinal pathologies: case report. J Neurosurg Spine 2017;26:513-8.
15. Smit TH, Muller R, van Dijk M, et al. Changes in bone architecture during spinal fusion: three years follow-up and the role of cage stiffness. Spine (Phila Pa 1976) 2003;28:1802-8; discussion 1809.
16. van Dijk M, Smit TH, Sugihara S, et al. The effect of cage stiffness on the rate of lumbar interbody fusion: an in vivo model using poly(l-lactic Acid) and titanium cages. Spine (Phila Pa 1976) 2002;27:682-8.
17. Nemoto O, Asazuma T, Yato Y, et al. Comparison of fusion rates following transforaminal lumbar interbody fusion using polyetheretherketone cages or titanium cages with transpedicular instrumentation. Eur Spine J 2014;23:2150-5.
18. Ware J, Kosinski M, Keller SD. A 12-Item Short-Form Health Survey: construction of scales and preliminary tests of reliability and validity. Med Care 1996;34:220-33.
19. Schimmel JJ, Poeschmann MS, Horsting PP, et al. PEEK Cages in Lumbar Fusion: Mid-term Clinical Outcome and Radiologic Fusion. Clin Spine Surg 2016;29:E252-8.

© Journal of Spine Surgery. All rights reserved.

20. Vadapalli S, Sairyo K, Goel VK, et al. Biomechanical rationale for using polyetheretherketone (PEEK) spacers for lumbar interbody fusion-A finite element study. Spine (Phila Pa 1976) 2006;31:E992-8.
21. Torstrick FB, Safranski DL, Burkus JK, et al. Getting PEEK to Stick to Bone: The Development of Porous PEEK for Interbody Fusion Devices. Tech Orthop 2017;32:158-66.
22. Tsou HK, Chi MH, Hung YW, et al. In Vivo Osseointegration Performance of Titanium Dioxide Coating Modified Polyetheretherketone Using Arc Ion Plating for Spinal Implant Application. Biomed Res Int 2015;2015:328943.
23. Spruit M, Falk RG, Beckmann L, et al. The in vitro stabilising effect of polyetheretherketone cages versus a titanium cage of similar design for anterior lumbar interbody fusion. Eur Spine J 2005;14:752-8.
24. Seaman S, Kerezoudis P, Bydon M, et al. Titanium vs. polyetheretherketone (PEEK) interbody fusion: Meta-analysis and review of the literature. J Clin Neurosci 2017;44:23-9.
25. Assem Y, Mobbs RJ, Pelletier MH, et al. Radiological and clinical outcomes of novel Ti/PEEK combined spinal fusion cages: a systematic review and preclinical evaluation. Eur Spine J 2017;26:593-605.
26. Mobbs RJ, Phan K, Assem Y, et al. Combination Ti/PEEK ALIF cage for anterior lumbar interbody fusion: Early clinical and radiological results. J Clin Neurosci 2016;34:94-9.
27. Buttermann GR, Glazer PA, Bradford DS. The use of bone allografts in the spine. Clin Orthop Relat Res 1996:75-85.
28. Phan K, Mobbs RJ. Evolution of Design of Interbody Cages for Anterior Lumbar Interbody Fusion. Orthop Surg 2016;8:270-7.
29. Kleinstueck FS, Hu SS, Bradford DS. Use of allograft femoral rings for spinal deformity in adults. Clin Orthop Relat Res 2002:84-91.
30. Rauzzino MJ, Shaffrey CI, Nockels RP, et al. Anterior lumbar fusion with titanium threaded and mesh interbody cages. Neurosurg Focus 1999;7:e7.
31. Ray CD. Threaded fusion cages for lumbar interbody fusions. An economic comparison with 360 degrees fusions. Spine (Phila Pa 1976) 1997;22:681-5.
32. Matge G, Leclercq TA. Rationale for interbody fusion with threaded titanium cages at cervical and lumbar levels. Results on 357 cases. Acta Neurochir (Wien) 2000;142:425-33; discussion 434.
33. Thalgott JS, Giuffre JM, Klezl Z, et al. Anterior lumbar interbody fusion with titanium mesh cages, coralline hydroxyapatite, and demineralized bone matrix as part of a circumferential fusion. Spine J 2002;2:63-9.
34. Burkus JK, Gornet MF, Dickman CA, et al. Anterior lumbar interbody fusion using rhBMP-2 with tapered interbody cages. J Spinal Disord Tech 2002;15:337-49.
35. Burkus JK, Schuler TC, Gornet MF, et al. Anterior lumbar interbody fusion for the management of chronic lower back pain: current strategies and concepts. Orthop Clin North Am 2004;35:25-32.
36. Godde S, Fritsch E, Dienst M, et al. Influence of cage geometry on sagittal alignment in instrumented posterior lumbar interbody fusion. Spine (Phila Pa 1976) 2003;28:1693-9.
37. McAfee PC. Interbody fusion cages in reconstructive operations on the spine. J Bone Joint Surg Am 1999;81:859-80.
38. Choi WS, Kim JS, Hur JW, et al. 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.
39. Lang G, Navarro-Ramirez R, Gandevia L, et al. Elimination of Subsidence with 26-mm-Wide Cages in Extreme Lateral Interbody Fusion. World Neurosurg 2017;104:644-52.
40. Cannestra AF, Peterson MD, Parker SR, et al. MIS Expandable Interbody Spacers: A Literature Review and Biomechanical Comparison of an Expandable MIS TLIF With Conventional TLIF and ALIF. Spine (Phila Pa 1976) 2016;41 Suppl 8:S44-9.
41. Mobbs RJ, Loganathan A, Yeung V, et al. Indications for anterior lumbar interbody fusion. Orthop Surg 2013;5:153-63.
42. Frisch RF, Luna IY, Brooks DM, et al. Clinical and radiographic analysis of expandable versus static lateral lumbar interbody fusion devices with two-year follow-up. J Spine Surg 2018;4:62-71.
43. Hawasli AH, Khalifeh JM, Chatrath A, et al. 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.
44. Calori GM, Colombo M, Mazza EL, et al. Incidence of donor site morbidity following harvesting from iliac crest or RIA graft. Injury 2014;45 Suppl 6:S116-20.
45. Laurie SW, Kaban LB, Mulliken JB, et al. Donor-

© Journal of Spine Surgery. All rights reserved.

site morbidity after harvesting rib and iliac bone. Plast Reconstr Surg 1984;73:933-8.
46. Slosar PJ, Josey R, Reynolds J. Accelerating lumbar fusions by combining rhBMP-2 with allograft bone: a prospective analysis of interbody fusion rates and clinical outcomes. Spine J 2007;7:301-7.
47. Stensby JD, Kaliney RW, Alford B, et al. Radiographic Appearance of Transforaminal Lumbar Interbody Fusion Performed With and Without Recombinant Human Morphogenetic Protein-2. AJR Am J Roentgenol 2016;206:588-94.
48. Miyazaki M, Tsumura H, Wang JC, et al. An update on bone substitutes for spinal fusion. Eur Spine J 2009;18:783-99.
49. Peterson B, Whang PG, Iglesias R, et al. Osteoinductivity of commercially available demineralized bone matrix. Preparations in a spine fusion model. J Bone Joint Surg Am 2004;86-A:2243-50.
50. Hoffmann MF, Jones CB, Sietsema DL. Adjuncts in posterior lumbar spine fusion: comparison of complications and efficacy. Arch Orthop Trauma Surg 2012;132:1105-10.
51. Zhang H, Wang F, Ding L, et al. A meta analysis of lumbar spinal fusion surgery using bone morphogenetic proteins and autologous iliac crest bone graft. PLoS One 2014;9:e97049.
52. Agarwal R, Williams K, Umscheid CA, et al. Osteoinductive bone graft substitutes for lumbar fusion: a systematic review. J Neurosurg Spine 2009;11:729-40.

Cite this article as: Patel DV, Yoo JS, Karmarkar SS, Lamoutte EH, Singh K. Interbody options in lumbar fusion. J Spine Surg 2019;5(Suppl 1):S19-S24. doi: 10.21037/jss.2019.04.04

© Journal of Spine Surgery. All rights reserved.