Review Article

Interbody options in lumbar fusion

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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

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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 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 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 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.

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Footnote

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

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