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CURRENT CONCEPTS IN SPINAL FUSION/REVIEW ARTICLE

Interbody Fusions in the Lumbar Spine: A Review

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Abstract *Background:* Lumbar interbody fusion is among the most common types of spinal surgery performed. Over time, the term has evolved to encompass a number of different approaches to the intervertebral space, as well as differing implant materials. Questions remain over which approaches and materials are best for achieving fusion and restoring disc height. *Questions/Purposes:* We reviewed the literature on the advantages and disadvantages of various methods and devices used to achieve and augment fusion between the disc spaces in the lumbar spine. *Methods:* Using search terms specific to lumbar interbody fusion, we searched PubMed and Google Scholar and identified 4993 articles. We excluded those that did not report clinical outcomes, involved cervical interbody devices, were animal studies, or were not in English. After exclusions, 68 articles were included for review. *Results:* Posterior approaches have advantages, such as providing 360° support through a single incision, but can result in retraction injury and do not always restore lordosis or correct deformity. Anterior approaches allow for the largest implants and good correction of deformities but can result in vascular, urinary, psoas muscle, or lumbar plexus injury and may require a second posterior procedure to supplement fixation. Titanium cages produce improved osteointegration and fusion rates but also increase subsidence caused by the stiffness of titanium relative to bone. Polyetheretherketone (PEEK) has an elasticity closer to that of bone and shows less subsidence than titanium cages, but as an inert compound PEEK results in lower fusion rates and greater osteolysis. Combination PEEK–titanium coating has not yet achieved better results. Expandable cages were developed to increase disc height and restore lumbar lordosis, but the data on their effectiveness have been inconclusive. Three-dimensionally (3D)-printed cages have shown promise in biomechanical and animal studies at increasing fusion rates and reducing subsidence, but additive manufacturing options are still in their infancy and require more investigation. *Conclusions:* All of the approaches to spinal fusion have plusses and minuses that must be considered when determining which to use, and newer-technology implants, such as PEEK with titanium coating, expandable, and 3D-printed cages, have tried to improve upon the limitations of existing grafts but require further study.

Keywords lumbar interbody fusion · ALIF · OLIF · LLIF

Introduction

Lumbar interbody fusion is used in the treatment of spinal pathologies resulting from degenerative disease, deformity, trauma, infection, and neoplastic and other conditions [66]. Developed as an alternative to posterolateral fusion techniques, interbody fusion involves removing the intervertebral disc and inserting an implant or graft and has been associated with reduced rates of post-operative complications and pseudarthrosis [15].

This technique was first described by Briggs and Milligan in 1944, who used a posterior approach to lumbar interbody fusion [8]. Over time, many other techniques have been developed that involve other approaches, including anterior, direct lateral, oblique lateral, and transforaminal. Evidence supporting the clinical superiority of one of these approaches over the others is inconclusive—each has advantages and disadvantages—and certain approaches can involve minimally invasive techniques to achieve interbody fusion.

The types of implant used in interbody fusion vary as well. The most commonly used materials for interbody fusion grafts are titanium and polyetheretherketone (PEEK). Although the sizes of most interbody fusion grafts currently in use are unchangeable, newer technologies involving expandable cages to increase disc height and restore lumbar lordosis have been

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introduced. Finally, new studies have investigated "additive manufacturing," including three-dimensional (3D) printing, of grafts that can be used in interbody fusion.

This article reviews the major approaches (directional and methodological) to lumbar interbody fusion, the various options for graft or cage materials, and the advent of new cage types.

Methods

In order to identify studies related to interbody fusion techniques and devices, we used the following search terms and Boolean operators to search PubMed and Google Scholar: lumbar interbody fusion AND device, posterior lumbar interbody fusion, lateral lumbar interbody fusion, transforaminal lumbar interbody fusion, PEEK cage AND spine, oblique lateral interbody fusion, anterior lumbar interbody fusion. The search yielded 4993 articles. We excluded articles that did not report clinical outcomes, involved cervical interbody devices, were animal studies, or were not published in English. After application of the exclusion criteria, 68 articles were included for review.

Results

Posterior Approaches to Spinal Fusion

Posterolateral Lumbar Interbody Fusion

Posterolateral lumbar interbody fusion (PLIF) was one of the first methods of interbody fusion described. Surgical access to the intervertebral disc space is achieved using a posterior approach with the patient in a prone position. Once the correct spinal level is identified, a laminotomy is performed medial to the facet joint and the thecal sac is retracted to expose the intervertebral disc space. PLIF can be achieved using an open method or a minimally invasive technique using the Wiltse muscle–splitting approach [20]. This technique is appropriate for patients with degenerative pathologies that make fusion necessary. Patients with lumbar stenosis, instability, pseudarthrosis, or recurrent disc herniation may benefit from PLIF, which is used to increase the area of fusion and indirectly decompress a neural foramen; the disc space height is increased, and complete removal of a facet joint is not necessary, which allows preservation of stability at an intervertebral level [48]. The major advantage of PLIF is that it is the surgical approach most familiar to spine surgeons. It also allows for visualization of the nerve roots without mobilizing major vessels, nerves, or muscles. Achieving neural decompression and restoring interbody height are readily accomplished with PLIF [36]. Moreover, PLIF allows for anterior and posterior support through a single incision and approach.

Iatrogenic injury is possible with PLIF because retraction of muscles and the thecal sac is necessary to access the intervertebral space [16]. Retraction injury to the nerve roots is a risk with this approach and can result in radiculopathy or fibrosis [24, 77].

Transforaminal Lumbar Interbody Fusion

Transforaminal lumbar interbody fusion (TLIF) is another posterior surgical approach used for interbody fusion. TLIF allows for direct, unilateral access to the intervertebral space while reducing the amount of direct dissection and retraction of the muscles, thecal sac, and nerve roots. The intervertebral space is accessed using a unilateral laminectomy and removal of the inferior facet. TLIF can be performed using an open procedure or a minimally invasive technique such as a paramedian Wiltse or tubular approach [20, 29]. TLIF can be used in the management of all types of spinal pathologies, ranging from degenerative disease to instability to trauma. In addition to requiring less retraction than PLIF, TLIF provides bilateral anterior and posterior support through just one surgical procedure [4, 22, 61], although it can fall short in correcting coronal deformities or restoring lordosis [24, 44, 68].

Anterior Approaches to Spinal Fusion

Anterior Lumbar Interbody Fusion

Anterior lumbar interbody fusion (ALIF) uses an anterior retroperitoneal approach to expose the entire ventral surface of the intervertebral space. This allows for a much larger implant to be placed over a much larger surface area of bone in the intervertebral space and therefore leads to better correction of coronal imbalance, greater restoration of lordosis, and high fusion rates [22, 32, 41, 61, 64]. ALIF also allows for sparing of the posterior paraspinal ligaments and muscles, maintains the posterior tension band for postural support, and reduces post-operative pain from muscle dissection. However, one drawback of ALIF is that some levels cannot easily be visualized. Levels cephalad to L4–L5 are obscured by vascular anatomy, which may require extensive retraction of peritoneal and renal structures. Additionally, ALIF may require a secondary posterior approach to achieve 360° support, particularly in isthmic spondylolisthesis at L5–S1 [63, 65]. Furthermore, ALIF can result in approach-related complications such as sexual dysfunction, retrograde ejaculation, or urinary incontinence in male patients and vascular injury in all patients [41, 50, 61, 74]. These risks are inherent in an anterior approach to the lumbar spine because of the proximity of the iliac arteries and veins, as well as the sympathetic plexus.

Studies comparing ALIF with posterior approaches highlight the advantages and disadvantages of each technique. One meta-analysis comparing ALIF with TLIF showed lower rates of dural injury but higher rates of blood vessel injury in the ALIF group. No differences were seen in neurological deficit, infection rates, or fusion rates [61]. Another study showed greater disc height, segmental lordosis restoration, and total lumbar lordosis in an ALIF cohort than in a TLIF group [22]. ALIF has also been shown to result in greater foraminal height than TLIF [64]. Another study found that ALIF patients had a higher reoperation rate within 2 years and a higher complication rate, in comparison with a TLIF group [23]. ALIF patients were also found to have shorter surgery times and lower rates of urinary tract infection but more pulmonary complications and longer hospital stays than TLIF patients [73]. However, although studies have shown ALIF to provide better disc and foraminal height, as well as restoration of lordosis, no studies have shown a difference in fusion rates between ALIF and posterior interbody approaches [14, 17, 30].

Lateral Lumbar Interbody Fusion

Lateral lumbar interbody fusion (LLIF) employs a lateral retroperitoneal approach to access the intervertebral space. This involves having the patient in the lateral position and requires dissection through the psoas muscle and lumbar plexus. With LLIF, access is possible from T12–L1 to L4–5, although not at L5–S1 because of the position of the iliac crests. LLIF can be used to restore sagittal and coronal balance, especially when laterolisthesis is present [3]. However, LLIF may not be adequate in patients with severe central stenosis, previous retroperitoneal surgery, or abnormal neurovascular anatomy [42, 43]. LLIF can achieve deformity correction with large interbody implants and high fusion rates [15, 60], although these come with heightened risks of vascular injury or injury to the psoas muscle, lumbar plexus, or bowel [3, 5, 21, 35, 40, 76]. As with ALIF, LLIF can provide an anterior strut but requires a secondary posterior procedure to attain 360° support and reduce the risk of graft subsidence [2, 7].

Given the relatively recent development of LLIF, there have not been many studies comparing LLIF with posterior approaches. One meta-analysis compared minimally invasive TLIF with LLIF and found that there were no differences in fusion or complication rates. However, it did find that minimally invasive TLIF patients had better Oswestry Disability Index (ODI) and visual analog scale (VAS) pain scores when compared with LLIF patients [28].

Oblique Lumbar Interbody Fusion

Oblique lumbar interbody fusion (OLIF) is an alternative to LLIF in achieving access to the intervertebral space. It reduces the risks of injury to the psoas muscle and lumbar plexus. Patients are positioned laterally, and entry is made through the retroperitoneal space, as in LLIF, but the approach to the intervertebral space is made anterior to the psoas muscle and lumbar plexus. OLIF can be performed throughout the lumbar spine, and access to the intervertebral space is not hindered by the position of the iliac crests. OLIF maintains the advantages of anterior access such as deformity correction and high fusion rates while saving on the biggest disadvantages of LLIF [37, 46, 56, 59, 72]. However, it can also result in sympathetic dysfunction and vascular injury, although at lower rates than with ALIF [37, 46, 59].

A study comparing patients undergoing OLIF and LLIF found that the LLIF group had a higher risk of motor deficits but also achieved greater correction of coronal deformity. The study also found that OLIF conferred a higher risk of vascular injury but achieved greater correction of sagittal deformities. The study found no between-group differences in patient-reported outcomes [47].

Another study compared OLIF with minimally invasive TLIF and found that patients had similar improvements in ODI and VAS scores. However, the study found that operating room time and estimated blood loss were higher in the minimally invasive TLIF group. Additionally, OLIF was associated with greater disc height and earlier time to fusion, as measured at 6 months, than minimally invasive TLIF. However, no difference was found in complication rates between the two approaches [39].

Traditional Implants

Titanium Implants

Titanium has been used as an orthopedic implant material since the 1940s [10]. It was the first graft material used for interbody fusion because of its resistance to corrosion, low density, and capacity for osteointegration [10, 51, 62]. Titanium cages were effective in achieving fusion, although a propensity for subsidence was a notable disadvantage [9, 11, 53]. This settling of titanium cages into adjacent vertebral bodies was hypothesized to be a result of the vast difference in rigidity between titanium (as measured using Young's modulus of elasticity) and the bone of the vertebral body [27]. Although not always clinically significant, rates of subsidence with anterior cervical discectomy and fusion have been found to be as high as 24.9% [55].

PEEK Implants

In response to the subsidence seen with titanium cages, PEEK was introduced as an interbody fusion graft. PEEK's modulus of elasticity is lower than titanium's and closer to that of bone. This results in less stress shielding and decreased subsidence and higher fusion rates [69]. PEEK has been used in all approaches to interbody fusion. One study looking at ALIF with PEEK found a fusion rate of 90.6% and a subsidence rate of 16% [6]. Another analyzed PEEK in minimally invasive TLIF and found a subsidence rate of 14.8% at 2 years' follow-up [31]. Similarly, a study examining PEEK in LLIF found the subsidence rate to be 14.3% [34]. PEEK is also radiolucent, which permits better assessment of fusion status on radiography than does radiopaque titanium. Additionally, PEEK is an inert compound, resisting cell adhesion, which makes it ideal for avoiding infection [19, 26]. However, this same property also makes it difficult for bone to integrate effectively into PEEK implants [13, 54].

PEEK Versus Titanium Implants

In a systematic review of studies comparing PEEK and titanium implants for interbody fusion, Seaman et al. found lumbar interbody fusion rates to be higher with titanium than with PEEK (86.2% versus 78.9%); not surprisingly, they found higher subsidence rates in titanium than in PEEK (35% versus 28%) [71]. Nemoto et al. performed a retrospective review of prospectively collected data comparing patients who underwent single-level TLIF with a titanium or PEEK cage. At 1 year of follow-up, computed tomographic

(CT) scans revealed the titanium group to have a 96% fusion rate, which increased to 100% by 2 years. In the PEEK cohort, the fusion rates were 64% at year 1 and 76% by year 2. Additionally, the patients in the PEEK group who did not achieve fusion were often found to have osteolysis [52]. Another study comparing PEEK and titanium cages in interbody fusion also found a higher fusion rate with titanium and increased osteolysis with PEEK implants [12].

New-Generation Implants

PEEK Implants with Titanium Coating

Given their positive attributes, PEEK and titanium have been combined into single interbody implants. Mobbs et al. studied a titanium-coated PEEK ALIF cage and achieved a fusion rate of 95% [49]. Rickert et al. performed a randomized, controlled trial comparing PEEK and PEEK with a titanium coating [67]. Patients had a one- or two-level TLIF, and fusion rates were determined on CT scans. The researchers found no difference in fusion rates between the two groups.

Expandable Implants

Sagittal balance and restoration of lumbar lordosis have been shown to improve clinical outcomes and pain in patients undergoing spinal surgery [33, 38, 70]. TLIF has been shown to be inadequate for achieving lumbar lordosis because of its inability to lengthen the anterior column of the spine [18, 22, 25, 38, 61]. Expandable cages were developed to help achieve this lengthening in a posteriorly approached fusion such as TLIF.

Alimi et al. studied radiographic and clinical outcomes in 49 patients who underwent TLIF with placement of an expandable PEEK cage [1]. Clinical outcomes were measured with the ODI and a VAS. A minimum clinically important difference on the ODI was achieved in 64% of patients and on a VAS back-specific measure in 52%. There were increases in average disc height and foraminal height and a reduction in listhesis.

However, a study by Yee et al. yielded less encouraging results [75]. They performed a retrospective cohort study of patients undergoing single-level TLIF with either an expandable cage or a static cage to determine which type of cage was better able to improve lumbar lordosis. The study population included 48 static-cage recipients and 41 expandable-cage recipients. Lordosis was measured on radiographs. The authors found no difference in either segmental or total lumbar lordosis between the two groups.

3D-Printed Cages

Given the shortcomings of both PEEK and titanium grafts, 3D printing has been used to improve interbody fusion. Because intervertebral cages are inherently mechanical in nature, biologic agents have been added to achieve fusion. One technique being used to improve the biologic function of existing implants is to treat cage surfaces with osteoconductive biomaterials to increase the rate of fusion and improve the osteointegration of the implant [57, 58]. Additive manufacturing, including 3D printing, can control the strut size, orientation of surface additions, and porosity of cages and improve their biomechanical properties. However, this is very new technology and studies are currently limited to biomechanical or animal investigations.

Zhang et al. performed a biomechanical study with finite element models comparing 3D-printed porous-coated titanium cages with PEEK and solid titanium cages [78]. PEEK and fully coated porous titanium cages reduced cage and end-plate maximal stresses in all planes of motion. Within the fully coated porous titanium cages, cage and end-plate stresses decreased with increased porosity.

McGilvray et al. performed a comparative study of 3D-printed porous titanium cages with PEEK and titanium-coated PEEK in a sheep model of lumbar interbody fusion [45]. Fusion was determined using micro-CT scanning. 3D-printed porous titanium cages were shown to reduce the range of motion in flexion–extension testing and increase stiffness, as compared with the other two types of cages. Additionally, 3D-printed porous titanium cages were found to have greater bone volume than the PEEK and titanium-coated PEEK cages.

Compliance with Ethical Standards

Conflict of Interest: Ravi Verma, MD, MBA, and Sohrab Virk, MD, MBA, declare that they have no conflicts of interest. Sheeraz Qureshi, MD, MBA, reports receiving consulting fees or royalties from Stryker, K2M, Paradigm Spine, Globus Medical, Medical Device Business Services, and Pacira Pharmaceuticals; owning shares of Avaz Surgical and Vital 5; and receiving royalties from RTI and Zimmer Biomet, outside the submitted work.

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