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Cages: designs and concepts

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Abstract Many new interbody fusion cages have been recently developed, but clinical studies analyzing fusion outcome are still scarce. Radiological methods to assess fusion are not standardized and are often unreliable. Cages have been stated to provide good segmental distraction, provide axial load support and reduce segmental mobility, but there have been reports of failed fusions because of implant failure. This paper presents a critical opinion on current cage designs, stressing their clinical and biomechanical implications. Threaded cage designs compromise endplate integrity, and when placed in pairs have inherent limitations for distraction. Non-threaded cage designs usually preserve endplate integrity, but geometry may be inadequate to provide a good surface match to the endplate. The concept of an open frame type cage is believed to have biological advantages, because large graft volumes inside the cage can be in direct contact with host bone. Cadaveric tests suggest that open frame constructs have compressive strength similar to that of full surface contact cages. Restoration of segmental height, sagittal balance and increased neuroforaminal clearance are all functions of disc space distraction. The effect of cage instrumentation on axial load distribution, however, is not well understood. Biomechanical experiments strongly suggest supplementing cage instrumentation with posterior fixation, to achieve a marked increase in initial segmental stability. In the absence of gross segmental instability, micromotion at the host graft interface may still exist. As a result, fusion will never occur, instead a pseudoarthrosis will develop. For monitoring fusion, the use of non-metallic cages has distinct advantages, because no metal artifacts will disturb radiological assessment.

Key words Cage design · Interbody fusion · Segmental distraction · Initial stability · Clinical fusion assessment

Introduction

Cage technology has profoundly changed the approach to spinal fusion, and there has been a resurgence of interest in performing interbody fusion. Since the pioneering work of Bagby in 1988 [2], new cage designs for use in the lumbar and cervical spine have continually evolved. Interbody fusion procedures using cage technology have also kindled interest in minimally invasive surgical techniques applied to modern spine surgery. Along with the less invasive surgical techniques that have evolved (laparoscopic [13] or minimally open [1] anterior spine surgery), and because the cage provides the required structural support, bone graft harvesting techniques have likewise become less invasive [18]. Only small amounts of cancellous bone are required, because there is no longer a need for the graft to be structural. These developments

may reduce post-operative morbidity otherwise associated with conventional cortico-cancellous iliac bone graft harvest.

Cages are said to offer distinct biomechanical advantages. They provide initial distraction and support axial load, thereby eliminating the need for structural support provided by the bone graft. Cages also provide initial segmental stability by tensioning the ligamentous apparatus. This tension anchors the cage's top and bottom faces to the adjacent endplates. However, cages have also been reported to subside [4], migrate [15] or mechanically fail [23]. There is concern over whether the favorable 2-year postoperative fusion rates of over 90% for stand-alone cages [9], as determined on flexion/extension views, will in fact be confirmed by long-term patient outcomes [14].

A large number of cages are currently available on the market, and undoubtedly even more will become available in the future. Given the many features claimed by manufacturers to be important for differentiation, there is a need in providing a rationale for the clinical use of cages. This paper presents a critical opinion on:

1. Current designs of fusion cages and their surgical implications
2. The influence of the cage geometry on axial load support and biological environment
3. Adequate disc space distraction
4. Initial stability and requirement for supplemental posterior fixation
5. Clinical fusion assessment.

Designs of fusion cages

Singular lumbar cage designs (SynCage, Mathys Medical Ltd., Bettlach, Switzerland; Anterior Lumbar Brantigan I/F, Depuy-Acromed Corp., Cleveland, Ohio; and others) are intended for anterior procedures. Some paired cage designs are used strictly for posterior procedures (Contact Fusion Cage, Stratec, Oberdorf, Switzerland; Posterior Lumbar Brantigan I/F, and paired Harms mesh cages, both Depuy-Acromed Corp., Cleveland, Ohio; and others), while others can be inserted using either an anterior or posterior procedure (BAK, Sulzer-Spinetech, Minneapolis, Minn.; Ray Cage, Surgical Dynamics, Norwalk Conn.; and others). Although paired cage designs are the most widely used, regulatory bodies often limit their use to specific surgical approaches or impose the condition that they be used in conjunction with posterior fixation. Despite the confusingly large number of marketed products, cages can all be classified based on their design into one of two types:

Cylindrical or conical cages

Cylindrical or conical cages (also referred to as threaded cages), are usually paired in the lumbar region, and are inserted parallel in an antero-posterior direction. Before implant insertion, these implants require preparation of the bony endplates with a reamer, followed by a threading device. The bony endplate's integrity therefore is partially destroyed, but the implant can achieve a good surface match with the underlying cancellous bone bed. An inherent problem with cylindrical designs is that the lateral width of a paired cage construct is at least double the cage height. Given the reaming depth (3-mm on either side) the distractive height of cylindrical cages is somewhat limited, because the construct's tolerated lateral width is restricted by the vertebra's anatomy.

Box-shaped or rectangular cages

Box-shaped or rectangular cages (also referred to as non-threaded cages) are placed, dependent on the surgical approach, singularly or in pairs. Most, allow placement of bone graft inside and around the cage. The preparation of the cage bed requires removal of the endplate cartilage, so that bleeding bone is exposed to the graft material. Assuming a careful preparation technique and gentle cage insertion, the integrity of the bony endplate can normally be preserved. Some cage designs attempt to mimic the inverse shape of the endplate's concave contour for an optimal surface fit, whereas others do not. Many feature saw teeth, spikes or a rippled contact surface for improved anchorage to the endplate.

Provision of axial support and post-operative segmental stability are the initial requirements for any instrumentation. Later, for the fusion to become stable, an optimal biological milieu for arthrodesis becomes the foremost concern. It has long been stressed that complete excision of the nucleus pulposus and endplate cartilage is important. Preparation of the host bone bed for threaded cages with a reamer does not allow complete excision of nucleus and endplate cartilage, which may impede fusion. Preparing an anterior window to allow for extensive disc removal before reaming and tapping may be advantageous.

Cage geometry: axial load support and biological environment

For successful fusion, it appears logical to strive for the smallest possible cage volume so that more graft material can be packed into the prepared disc space. The larger the interface between bone graft and a correctly prepared host bed, the more likely fusion will be. The cylindrical geometry of paired threaded cages accommodates less graft material than a singular box-shaped cage. Obviously there
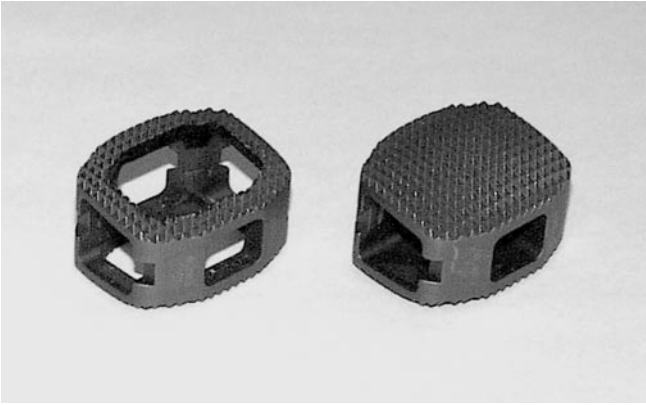
Fig. 1 Implant design with a central opening and a peripheral rim (*left*), and cage design with a solid face (*right*)
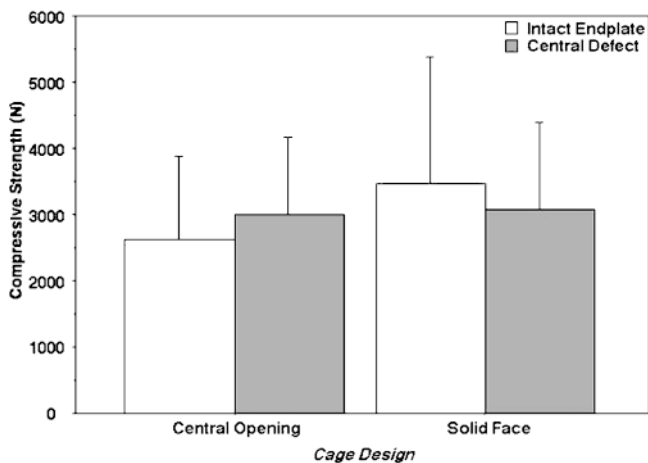
Fig. 2 Ultimate compressive strength (mean and standard deviation) for all experimental groups. No significant difference was found for either cage design or endplate preparation

is a tradeoff between minimizing the cage contact area with the bony endplate at the risk of experiencing implant subsidence, and maximizing the graft contact area to a prepared bleeding host bone bed for increasing the likelihood of a solid fusion.

In a recent study [19], we tested the compressive strength of two different cage designs and two different endplate preparation techniques. The two cage designs were based on the convex-shaped SynCage. The first had a solid endplate face providing 100% surface contact, the second had a large central opening (22×16 mm) machined into the face, leaving a 4-mm-wide perimeter in contact with the endplate for axial load support (Fig. 1). Both endplate preparation techniques used a curette to entirely remove the cartilaginous endplate, but the second technique also had a central defect precisely machined into the bony endplate, exposing cancellous bone to a depth of 2-mm. Ultimate compressive strength (Fig. 2) of each of the four possible combinations (two cage designs and two endplate

preparation techniques) was not significantly different. This finding suggests that a cage resting only on the peripheral area of the endplate (apophyseal ring) provides sufficient axial support. The advantage of this design is that graft material, placed inside the cage, can be in close contact with cancellous host bone on a large surface.

Disc space distraction

In another recent study [21] comparing the initial stability provided by different stand-alone anterior interbody fusion implants, we compared one threaded and four non-threaded implant designs for their ability to reduce segmental mobility. Multilinear regression analysis was used to identify the most important implant- and insertion-related measurements for predicting reduction of segmental motion and implant pullout strength. The two prominent parameters were the lateral implant width normalized to the endplate width, and the segmental distraction due to cage insertion. Similar findings were noted in a cervical biomechanical study (unpublished data, K. Yang et al., 1999) comparing the initial stability provided by five different stand-alone cages. Again, the distraction height and the normalized lateral cage diameter were the most important parameters in predicting initial stability.

To provide maximum initial stability and to accommodate a larger volume of graft material, it appears that a cage should be as wide as possible. Distraction also maximizes stability by tensioning the ligamentous apparatus. However, cadaveric experiments have two important limitations: The test specimens usually do not have severe degenerative changes followed by disc space narrowing, unlike patients in a clinical setting, and the ligamentous tension achieved by initial distraction may decrease later because of stress relaxation.

It is not understood how much disc space distraction is considered optimal. Not only too little, but also too much distraction is believed to compromise clinical outcome. For correct facet alignment and increased neuroforaminal clearance, restoration of the posterior disc height is crucial. Wedged anterior cages do not address this problem. Posterior cages, on the other hand, while more effective at restoring posterior disc height, may lead to segmental kyphosis and disturb the spine's sagittal balance. The effects of disc space distraction, segmental lordosis, and tensioning of the ligamentous apparatus on restoration of the sagittal balance and resulting load distribution across the instrumented motion segment have yet to be established.
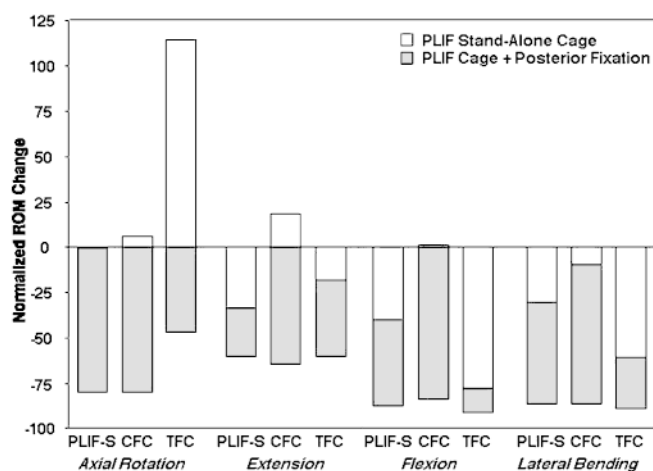
Fig. 3 Normalized to intact percentage changes in the range of motion (ROM) of three different cage constructs (PLIF-Spacer, Contact Fusion Cage and Ray TFC), used as stand-alone (*white bars*) and supplemented with pedicle screw fixation (*gray bars*)

Initial stability and supplemental posterior fixation

In the realm of minimally invasive surgery, placing an anterior stand-alone cage laparoscopically or minimally open would be desirable, but the initial stability provided by the cage alone may not be sufficient achieve fusion. To achieve fusion, large micromotion at the interface between graft and host bone is to be avoided. Biomechanical studies of posterior stand-alone cages, however, suggested these constructs largely fail to restrict extension and axial rotation movements [12]. Particularly for large posterior lumbar interbody fusion cages, insertion necessitates partial or complete resection of the facet joints, which further destabilizes the motion segment in axial rotation [26]. Micromotion in shear and distraction at the interface between graft and host bone are likely to persist.

Higher fusion rates have been reported for femoral ring allografts when supplemented with posterior translaminar screw fixation [8]. Likewise, threaded cages were reported to result in higher fusion rates when supplemented with pedicle screw fixation [24]. For threaded cages supplemented with pedicle screws, excellent 2-year fusion rates, has high as 94% [25] and 96.5% [10], have been reported.

In a recent study, we compared initial stability for three different posterior lumbar interbody fusion cages (PLIF-Spacer, Contact Fusion Cage and Ray TFC), with and without supplemental pedicle screw fixation [22]. Residual segmental mobility (Fig. 3) for the extension and lateral bending directions was quite similar for the non-threaded cages. The implants were least effective at reducing axial rotation. Threaded implants even showed an increase for axial rotation movements compared to intact specimens. None of the motion directions consistently showed re-

duced mobility after instrumentation with stand-alone cages. Addition of posterior fixation drastically reduced segmental mobility, to about one-sixth of the intact values, consistently for all implants and motion directions. Similar findings have been reported by others for anterior [6] and posterior [12] cage instrumentation, corroborating the need for supplemental fixation to increase initial stability.

The strength of a pedicle screw system may not be required for supplemental fixation along with a cage; instead, translaminar [16] or transarticular [3] facet screws may be used. Advantages of facet screws are the smaller amount of implant material placed, lower implant costs, and the possibility of performing minimally invasive percutaneous surgery. Biomechanical studies are however, required to compare the strength of cage instrumentation combined with either translaminar, transarticular or pedicle screw fixation.

A limitation of all cadaveric biomechanical studies is that findings for initial stability for different implant constructs are not helpful for predicting fusion. Even though it is generally accepted that initial stability is a requirement for fusion, how much residual segmental mobility or micromotion at the interface between graft and host bone can be tolerated has not been established. Stability is not an absolute notion. Even with the strongest fixation technique there always will be small movements. It is crucial to accept that regardless of how strong a fixation is, it will eventually experience fatigue failure without a solid fusion mass sharing axial load. Several reports [11, 23] on fatigue failures observed for interbody fusion cages support this statement.

Clinical fusion assessment

Stable fusion is the ultimate goal for any cage instrumentation, but monitoring the clinical fusion outcome is difficult [7]. The most sensitive diagnostic methods for detecting a pseudoarthrosis are computed tomography (CT) or magnetic resonance imaging (MRI). However, steel and titanium implants cause artifacts, rendering fusion assessment unreliable. Even plain radiographs pose a significant limitation, in that the radio-opaque implant is often superimposed on the fusion mass. Fenestrated cages may allow for an improved view, but never is the entire fusion mass visible for radiographic assessment.

Functional radiographs in flexion/extension would allow residual segmental mobility to be quantified, thus serving as an indirect measure for monitoring fusion success, but the absence of detectable motion does not imply that solid fusion has occurred [5]. A fibrous pseudoarthrosis may well limit gross segmental motion, but micromotion may persist, thus impeding fusion. Gross segmental stability, even in the absence of pain, does not imply successful fusion. The only acceptable criteria for clinical fu-

sion assessment is the presence of bridging trabecular bone in continuity across two adjacent vertebrae [14].

The availability of radiolucent non-metallic cages has improved MRI and CT assessment of a fusion mass. Most widely used are carbon fiber cages, but clinical experience has been disappointing because of synovitis and lymphatic spread of released fibers observed after intraarticular procedures [17]. Alternative materials such as polyetheretherketone (PEEK) alone or as a composite to embed free fibers may be an alternative. More recently, cortical allograft bone from controlled donor banks, machined to a shape similar to cages, has become available [20]. Advantages are that they can be inserted like traditional cages using standardized instrumentation including trial spacers and off-the-shelf implants. Remodeling of the cortical allograft may take years, but osteointegration can be monitored using plain radiographs. Finally, if revision surgery is required, no foreign body will have to be removed.

Conclusions

Cage designs have evolved over the past few years, but a thorough clinical assessment is not yet available. In particular, standardized criteria for measuring clinical outcome of interbody fusion are lacking. This paper presents a critical opinion on advantages and disadvantages of current cage designs for their ability to promote solid fusion. A wide open frame design, accommodating a large graft volume in direct contact with the host bone, appears to have biological advantages. Wider cages also increase initial stability. Biomechanical studies strongly suggest supplementing interbody fusion with posterior instrumentation to limit residual segmental mobility and micromotion. The distinct goals for restoration of segmental height, sagittal balance and increased neuroforaminal clearance all are linked, but the effect of disc space distraction provided by different cage designs with regard to achieving these goals is presently not understood. Ultimately, nonmetallic cages may be advantageous, because they allow for more reliable clinical fusion assessment.

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