REVIEW ARTICLE

Indications for Anterior Lumbar Interbody Fusion

Ralph J Mobbs, MD[1,2,3], Aji Loganathan, MD[1,3], Vivian Yeung, MD[1,3], Prashanth J Rao, MD[1]

[1]NeuroSpineClinic, [2]Department of Spine Surgery, Prince of Wales Private Hospital, Randwick, Sydney, and [3]University of New South Wales, New South Wales, Australia

Anterior lumbar interbody fusion (ALIF) has become a widely recognized surgical technique for degenerative pathology of the lumbar spine. Spinal fusion has evolved dramatically ever since the first successful internal fixation by Hadra in 1891 who used a posterior approach to wire adjacent cervical vertebrae in the treatment of fracture-dislocation. Advancements were made to reduce morbidity including bone grafting substitutes, metallic hardware instrumentation and improved surgical technique. The controversy regarding which surgical approach is best for treating various pathologies of the lumbar spine still exists. Despite being an established treatment modality, current indications of ALIF are yet to be clearly defined in the literature. This article discusses the current literature on indications on ALIF surgery.

Key words: Anterior lumbar interbody fusion; Indications

Introduction

Anterior lumbar interbody fusion (ALIF) has become a widely accepted surgical technique for various degenerative pathologies of the lumbar spine. Spinal fusion has evolved significantly since the first successful internal fixation by Hadra in 1891 who used a posterior approach to wire adjacent cervical vertebrae in the treatment of fracture-dislocation[1–4]. The use of autologous bone grafts began with Hibbs in 1910 when he used fragments of spinous processes and lamina to perform bony ankylosis in patients with Pott's disease (extrapulmonary tuberculosis) of the spine[1,5–7]. It was soon realised that immobilisation of the spine was the key to successful fusion and this marked the start of the hardware age featuring wiring techniques, facet and pedicle screws, and Harrington rods[8]. In 1932, Capener was the first to describe ALIF in the treatment of spondylolisthesis[5,9,10]. Since that time little progress was made with the ALIF technique until the 1980s. After 1980, several advancements were made to reduce morbidity including bone grafting substitutes, metallic hardware instrumentation, improved surgical technique and superior lighting and retraction[2,11–14]. However, the controversy regarding which surgical approach is best for treating various pathologies of the lumbar spine still exists[3,15–19]. Despite being an established treatment option, current indications of ALIF are yet to be clearly defined in the literature[20]. Note should be made that the ALIF technique is usually followed by some form of internal fixation, such as integral fixation within the ALIF implant, anterior plate fixation or posterior fixation such as pedicle screws. The literature is not been specific enough in terms of distinction of the additional fixation and therefore this article relates to ALIF as the primary procedure, with or without additional bone fixation.

Rationale

The indications for ALIF surgery depend largely on the surgeon and his/her comfort with the approach and procedure, and varies with the pathology from patient to patient[3,5]. Early in its history, ALIF was avoided due to difficult technical elements required in the surgery and approach based complications were considered too high a risk for the potential benefits[3,21–23]. Progress in recent times with instrumentation, retraction and approach issues has led to ALIF's status as a mainstay of spinal surgery particularly in degenerative pathologies as it restores biomechanical and structural integrity[3,5,21,24–29].

There are several advantages of the anterior approach to the lumbar spine. First and foremost, there is direct visualization and efficient access to the anterior column allowing for an easy and complete discectomy, better distraction increasing the neuroforaminal volume and the placement of a large

Address for correspondence Ralph J Mobbs, MD, NeuroSpineClinic, Prince of Wales Private Hospital, Randwick, Sydney, Australia 2031
Tel: 0061-2-96504766; Fax: 0061-2-48622176; Email: ralphmobbs@hotmail.com
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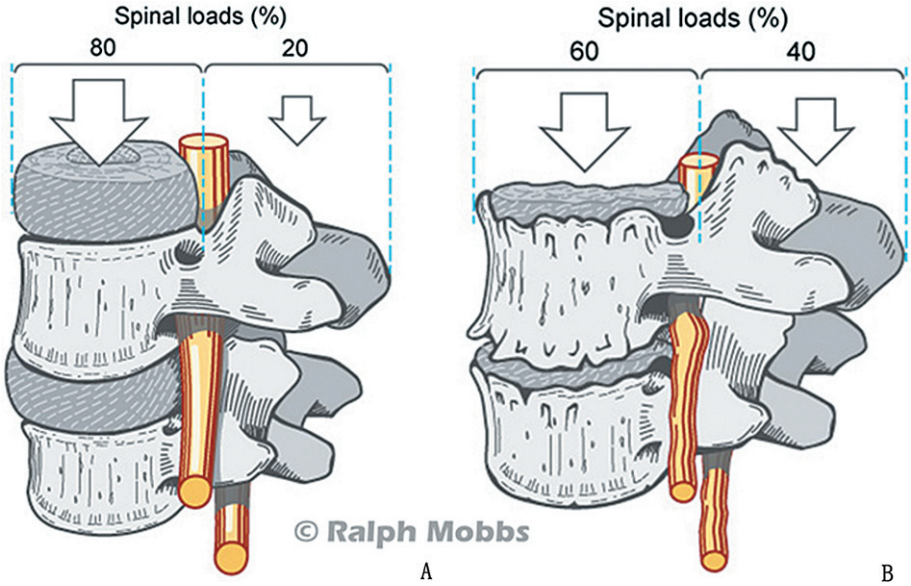

Fig. 1 (A) Distribution of spinal loads on the anterior and posterior weight-bearing columns in a normal lumbar spine. (B) Shifting of spinal loads to the posterior column after degenerative pathology to the lumbar spine.

interbody fusion device[2,3,21,23,25,26,30–33]. All these benefits contribute to higher fusion rates and potential positive clinical outcomes[5,25,30]. Furthermore, ALIF restores lumbar lordosis, reduces anterior listhesis with distraction, and achieves coronal and sagittal balance[2,3,31]. Additionally, this alleviates pain particularly because loss of physiological lordosis and sagittal imbalance is a potential cause of pain in the lumbar spine[23,34].

Reduced blood loss, short operative times and lack of blood transfusion are other advantages with ALIF compared to other approaches[2,21,25]. Burke reported an average blood loss of 200–300 mL during a single level surgery. ALIF has a relatively short operating time compared with posterior fusion surgery, and studies show that it can take 90 minutes or less[2,8,21]. Moreover, several studies show a reduced perioperative morbidity compared to other approaches resulting in shorter hospital stay and bed rest[25,30].

In a normal lumbar spine in the upright standing position, the anterior and middle weight-bearing columns of the spine support approximately 80% of spinal loads while the posterior column only supports 20%[23,31,35,36]. However, with aging and the consequences of the degenerative cascade including dehydration of the nucleus and repetitive annular injuries reducing the height of the disc, the weight bearing shifts such that the posterior column supports a greater percentage of the axial load (Fig. 1). With ALIF, the interbody fusion device is utilized to redistribute the weight-bearing to the original ratio. Furthermore, according to Woolf's Law, fusion potential increases if grafts are placed under direct compression which supports placement of the graft in the anterior column. Additionally, the anterior and middle columns provide 90% of the osseous surface area containing more vascularity than the posterolateral space and this wide cancellous bed for graft contact enhances the fusion potential[13,31]. This also facilitates placing a larger interbody device that contacts the apophyseal ring and increases the segmental lordosis[13]. While Chow *et al.* found "no relation between bony fusion and symptomatic relief", other studies show that there is generally correlation between successful fusion rate and good clinical outcomes[37]. However, it is possible to achieve a reasonable clinical outcome in cases of non-union and this is attributed to indirect nerve decompression and reduction of frontal or sagittal plane deformities[38,39].

Compared to posterior lumbar interbody fusion (PLIF) or the transforaminal route (TLIF), the retroperitoneal approach in ALIF spares iatrogenic trauma to the paraspinal musculature, posterior spinal nerves and posterior bony elements[25,30,31,40]. The lateral interbody technique (LLIF) has similar advantages[25], however, it is out of the scope of this article. Another advantage over the posterior approach is that nerve root retraction and entrance into the spinal canal is unnecessary and thus avoids epidural scarring and perineural fibrosis[2,5,41–43]. Furthermore, there is decreased morbidity from pulmonary complications with regard to other approaches[30].

The spine is usually a versatile structure taking part in a range of movements but it has been established that the key to any bony fusion is the successful immobilization of a joint[2]. Stabilizing the spine by fixation and induction of osteoblastic activity to form new bony trabeculae reduces pain, corrects deformity and improves arthrodesis[11]. Some reports show that pseudoarthrosis and non-union are a possible complication of stand-alone ALIF surgery and hence supplementary posterior instrumentation achieving circumferential fusion should be utilized[21,31,41]. Instead of two staged operation involving poster

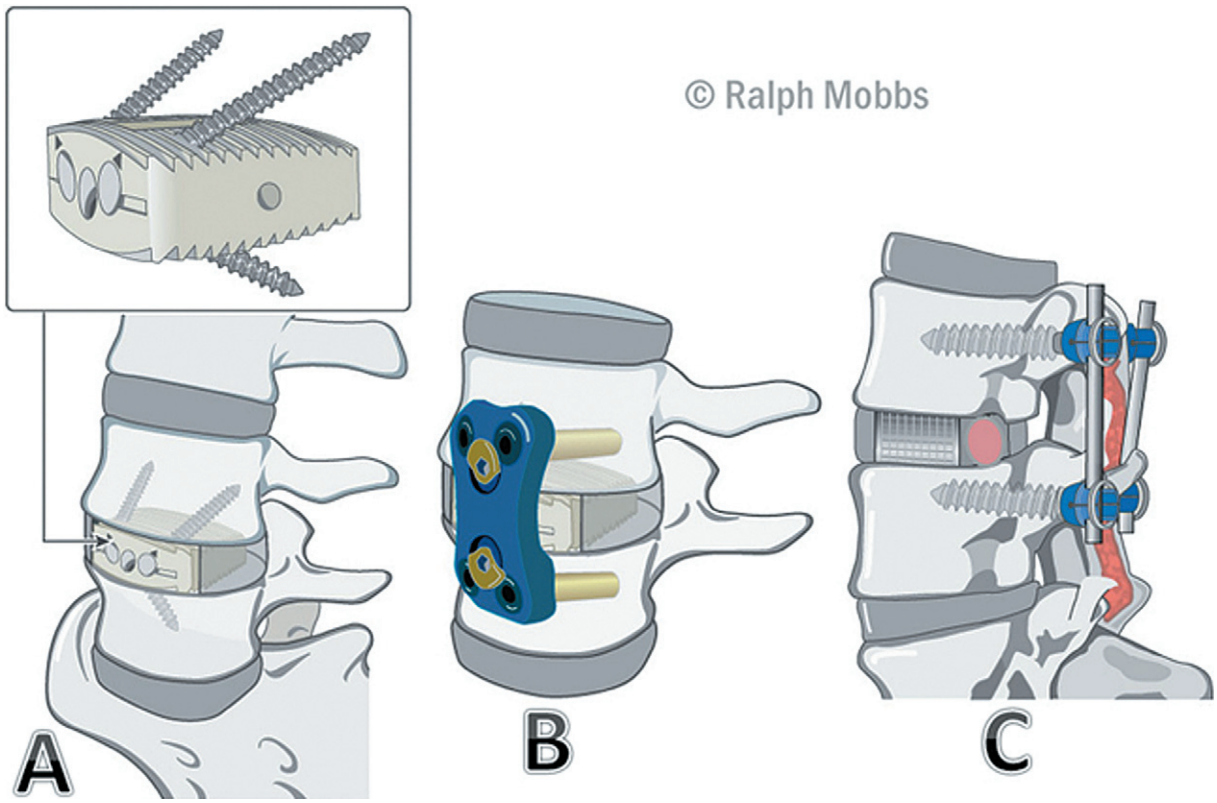

Fig. 2 (A) ALIF interbody device with integral fixation. (B) ALIF implant with anterior plate fixation. (C) ALIF implant with posterior instrumentation.

lateral instrumentation, which requires additional time, expense and morbidity, evidence shows that using a minimally invasive percutaneous pedicle screw fixation maintains fusion rates but has less perioperative morbidity[5,25,26,31,35,44–48]. Pedicle screws allow for strong fixation from the posterior elements to the anterior column allowing the spine to withstand correction forces[49–51].

There are many variations on ALIF surgery including bone grafting and implant/instrument options. There have been numerous publications reviewing the graft options for anterior cervical fusion with relatively fewer papers on ALIF graft options such as autografts, allografts, bone morphogenic proteins (BMP) and other bone graft substitutes[52–57]. Moreover, the ALIF interbody cages have different instrumentation namely ALIF with posterior instrumentation, ALIF with anterior plate and ALIF interbody device with internal fixation (Fig. 2).

While the long-term success rates of ALIF have made it a viable option for many indications, there have been complications. These complications can be considered as approach based or spine specific[58]. With the anterior approach, mobilization of the great blood vessels and peritoneal contents, and exposure of the superior hypogastric sympathetic plexus place them at risk of iatrogenic injury[13]. The literature reports a host of approach based complications but the most common are retrograde ejaculation, vascular injury, superficial infection, urological injury and abdominal muscle damage[59,60]. Retrograde ejaculation and sterility has been reported in many studies due to injury of the superior hypogastric sympathetic nerve plexus particularly when operating at L_4/L_5 level[2,3,5,21,30,31,61–64]. Vascular injury is more common when operating at L_4/L_5 level due to the anatomy of the iliac vessels and iliolumbar vein[13,65]. Spine specific complications include implant migration, graft collapse and expulsion and pseudoarthrosis[2,3,5,21,23,30,31,61].

Indications

The ideal candidate for ALIF has chronic, disabling back pain of discogenic origin for 1 or 2 levels with loss of height, stability and mobility of the diseased segment or neurological deficit[2,5,25,66]. All conservative, medical approaches must be exhausted and pain is refractory to these methods[2,25,67]. Patient selection is crucial for successful outcomes and they must not have contraindicating factors such as osteoporosis or infection[68]. ALIF is now a common procedure but its indications are controversial and confusing[3]. There have been numerous uses of ALIF in the past[69,70]. The following indications are the most commonly discussed in the literature.

Spondylolisthesis

Spondylolisthesis can be classified as isthmic, degenerative, dysplastic or traumatic. The literature illustrates that ALIF has

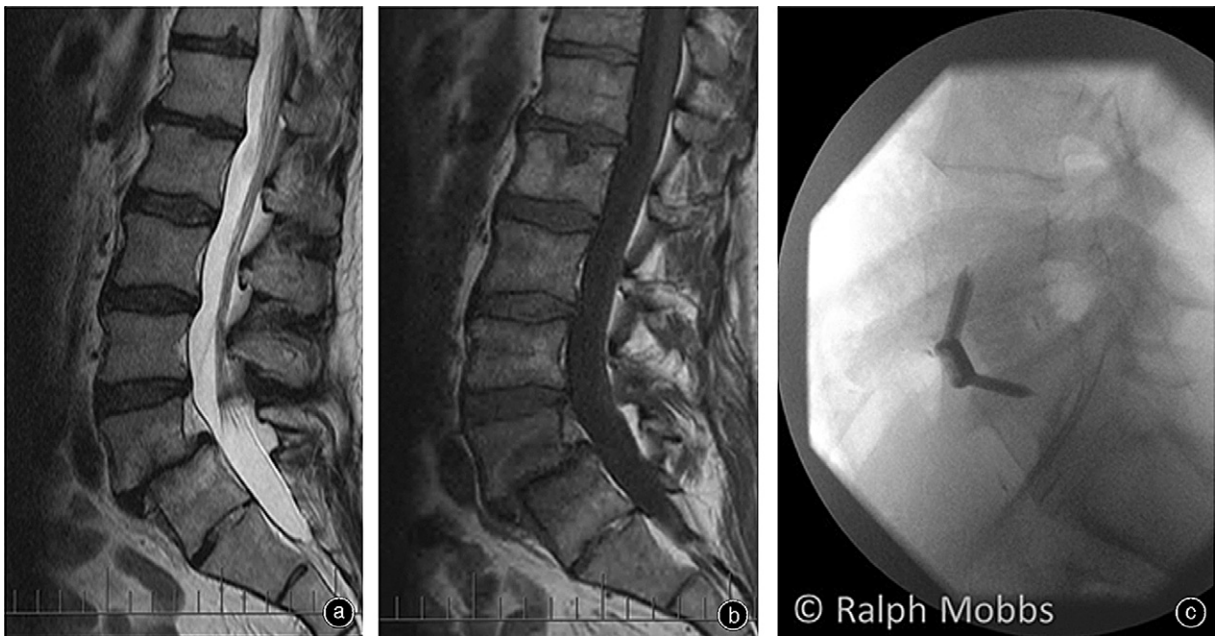

Fig. 3 (A) T_2 MRI of a L_5S_1 spondylolisthesis. (B) T_1 MRI of a L_5S_1 spondylolisthesis. (C) X-ray after ALIF surgery with internal fixation and interbody device.

been employed widely in two of these conditions, isthmic and degenerative spondylolisthesis, with good outcomes[71] (Fig. 3).

Isthmic spondylolisthesis occurs when there is a fracture to the pars interarticularis resulting in a forward listhesis[72]. If conservative measures are ineffective to treat the symptoms including lower back and radiating pain, neurologic dysfunction and abnormal posture and gait, ALIF is an effective long term treatment option as it provides slip reduction and a

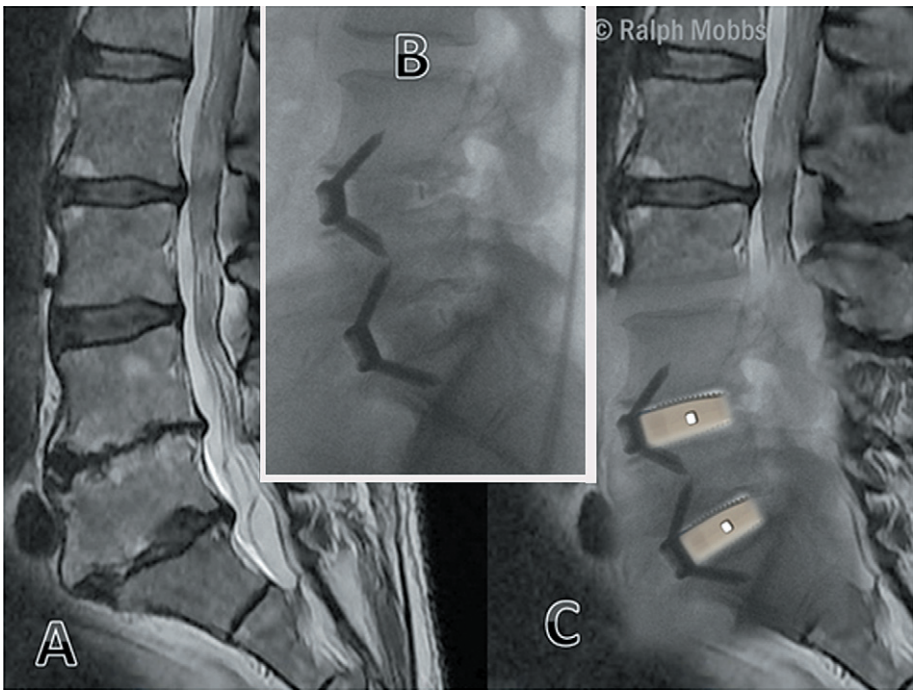

Fig. 4 (A) MRI showing degenerative disc disease with foraminal stenosis at the L_{4-5} and L_5S_1 levels prior to ALIF surgery. (B) Post-operative X-ray with anterior interbody fusion at L_{4-5} and L_5S_1. (C) Onlay of MRI-X-ray showing the interbody device.

TABLE 1 Summary of clinical studies with spondylolisthesis as the indication for ALIF[25,26,29,39,71,76,80,83–85]

Author	Study type	Indication	Surgery	Number of patients	Fusion rates (%)	Clinical success rate (%)	Serious complication rate (%)	Comments
Takahashi *et al.*, 1990	Retrospective study	Degenerative spondylolisthesis	ALIF	39	90	76	3	
Satomi *et al.*, 1992	Retrospective study	Degenerative spondylolisthesis	ALIF	27	96	93	4	
Muschik *et al.*, 1997	Retrospective study	Isthmic spondylolisthesis	ALIF	29	76	69	7	Isthmic spondylolisthesis in children and adolescents aged under 19 years
Muschik *et al.*, 1997	Retrospective study	Isthmic spondylolisthesis	ALIF + PSF	30	93	83	13	Isthmic spondylolisthesis in children and adolescents aged under 19 years
Kim and Lee, 1999	Retrospective study	Isthmic spondylolisthesis	ALIF	20	90	85	25	
Ishihara *et al.*, 2001	Retrospective study	Isthmic spondylolisthesis	ALIF	35	83	—	—	12 dropped out of this study
Johnson *et al.*, 1988	Retrospective study	Isthmic spondylolisthesis	ALIF +(–) PSF	44	96	96	11	Some cases included instrumentation with either posterior or Fibular interbody strut and H-rods
Christensen *et al.*, 1996	Retrospective study	Isthmic spondylolisthesis	ALIF	57	47	76	7	
Lee *et al.*, 2004	Retrospective study	Isthmic spondylolisthesis	ALIF + PSF	73	97	94	16	
Shim *et al.*, 2011	Retrospective study	Isthmic spondylolisthesis	ALIF + PSF/PLF	49	84	88	4	
Kim *et al.*, 2010	Retrospective study	Isthmic spondylolisthesis	ALIF + PSF	63	100	89	—	Low-grade adult spondylolisthesis
Suk *et al.*, 2001	Retrospective study	Spondylolisthesis	ALIF + PSF	21	100	—	14	
Min *et al.*, 2007	Retrospective study	Spondylolisthesis	ALIF	25	100	92	16	

ALIF, anterior lumbar interbody fusion; PLF, posterolateral fusion; PSF, pedicle screw fixation.

biomechanical solution to the anterior translational instability[39,73]. Radical discectomy and restoration of intervertebral height maintained by an interbody graft achieve indirect foraminal decompression[39,74]. Non-union has been reported, resulting in residual lower back pain. Despite this, the literature shows that ALIF is a long term solution to radicular symptoms such as leg pain, reduced walking ability, and neurological disturbances[75].

Ishihara *et al.* recommend the use of posterior instrumentation as there are higher long term fusion rates[39]. Additionally, Kim and Lee expressed the importance of post-operative immobilisation[76]. According to Kim *et al.*, these are the two most important factors to improve radiological and clinical outcomes[77].

Degenerative spondylolisthesis (DS) was noted by Newman in 1933 as the slippage of the vertebrae with an intact neural arch resulting from arthritic degeneration of the lumbar facet joints[78,79]. Most commonly seen in women at the L_{4-5} disc level, characteristic symptoms include lower back pain, leg pain and intermittent claudication. Pain in degenerative spondylolisthesis is produced by three different mechanisms. Listhesis causing concomitant spinal stenosis compounded by hypertrophy of the ligamentum flavum and osteophytes from facet arthritis encroaching into the spinal canal manifests as neurogenic claudication. Radicular pain occurs due to compression of the nerve root in the lateral recess or foramen. Mechanical low back pain is generated from degenerative intervertebral discs or arthritic facet joints. Apart from chronic pain, the other symptoms that warrant surgery include progressive neurological deficit and bladder or bowel dysfunction[78].

ALIF is indicated as it stabilises the spinal column, restores disc height indirectly decompressing nerve roots, removes the pain-generating intervertebral disc and posterior instrumentation corrects listhesis or kyphosis. Satomi *et al.* showed that ALIF had higher fusion rates, better clinical outcomes and less neurological deficits like dysesthesia and dysuria in Grade 1 and 2 DS[80].

Takahashi *et al.* in a study of 39 patients who underwent ALIF surgery for degenerative spondylolisthesis had a 76% clinical success rate and recommend that better long-term outcomes are experienced in patients under the age of 65 years[71]. The literature shows that fusion for spondylolisthesis is a better option than stand-alone decompression and indication for instrumentation remains controversial as it has a higher complication rate compared with graft only, but also a higher long term fusion rate[78,81,82]. Several studies support ALIF for both isthmic and degenerative spondylolisthesis with clinical success rates between 72% and 94%[25,26,39,76,80,83,84] (Table 1).

Degenerative Disc Disease

Degenerative disc disease (DDD) is a potentially painful condition that causes mechanical, chronic lower back pain and in a sizeable minority can limit function significantly[13]. DDD may be accompanied by foraminal stenosis due to loss of disc height, compressing the nerve root causing radiculopathy.

TABLE 2 Summary of clinical studies with degenerative disc disease as the indication for ALIF[21,23,28,41,91–97]

Author	Study type	Surgery	Number of patients	Fusion rates (%)	Clinical success rate (%)	Serious complication rate (%)	Comments
Newmen and Grinstead, 1990	Prospective study	ALIF	36	89	86	11	
Blumenthal *et al.*, 1987	Prospective study	ALIF	34	73	74	3	
Christensen *et al.*, 1996	Retrospective study	ALIF	63	58	76	7	
Boden *et al.*, 2000	Prospective randomized controlled trial	ALIF	14	93	86	NR	
Burkus *et al.*, 2002	Prospective, non-blinded study	ALIF	46	83	73	11	
Burkus *et al.*, 2002	Prospective, randomized, non-blinded	ALIF	279	92	81	9	
Kleeman *et al.*, 2001	Prospective, controlled, non-randomized	ALIF	22	100	100	0	
Sasso *et al.*, 2004	Prospective, randomized, controlled clinical trial	ALIF	140	77			
Strube *et al.*, 2011	Prospective cohort study	ALIF	40	71	91	6	6 patients dropped out
Moore *et al.*, 2002	Retrospective study	ALIF + PLF	58	95	86	5	
Matge & Leclercq, 2000	Retrospective study	ALIF	222	96	80	10	
Pavlov *et al.*, 2004	Prospective study	ALIF	58	99	98	10	

ALIF, anterior lumbar interbody fusion; NR, no record; PLF, posterolateral fusion.

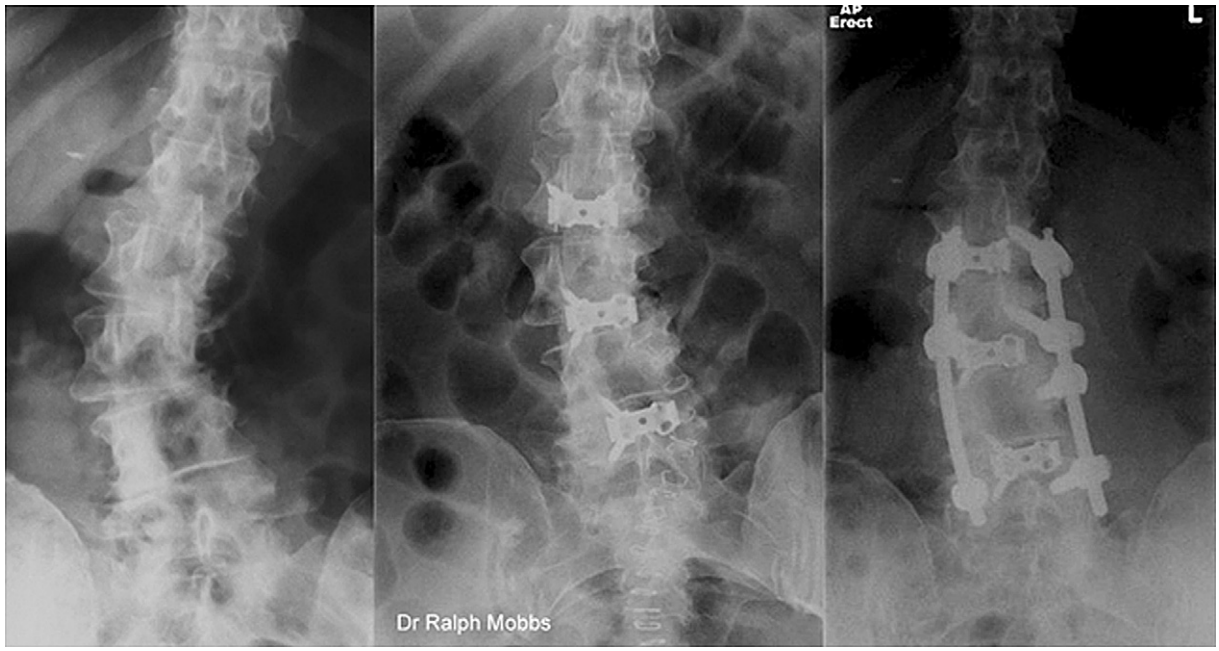

Fig. 5 Degenerative lumbar scoliosis managed with ALIF and percutaneous pedicle screw fixation.

DDD with mechanical pain is a different indication to cases with foraminal stenosis. In the literature, however, these two indications are often grouped under DDD.

In DDD with mechanical pain, the disc is considered the primary pain generator and therefore, surgical intervention is targeted at removing the intervertebral disc and restoring the structural and biomechanical integrity of the spinal column[3,86]. Delamination and degeneration of the disc, and posterior annular fissuring are causes of mechanical pain due to the mechanical loading to these areas resulting in sensitization of annular receptors[87]. During the degenerative cascade, neovascularization, neuronal penetration with unmyelinated nerve fibres and in-growth of Schwann cells occur and this neoinnervation is a potential pain generator[86]. Therefore, removing the vertebral disc is essential in pain reduction and implanting the interbody device restores segmental stabilization and corrects abnormal loading[13].

DDD with foraminal stenosis presents differently as the patient experiences an element of mechanical pain but the overriding issue is radiculopathy caused by nerve root compression[35,88,89]. Generally, segmental stenosis and radiculopathy is a result of disc herniation, posterior osteophyte formation, facets overriding and hypertrophy and infolding of the ligamentum flavum combining to reduce neuroforaminal volume[90] (Fig. 4).

Burkus *et al*. have completed the largest prospective study on DDD with 279 patients investigated after ALIF treatment. Clinical outcomes were based on comparing preoperative and postoperative Oswestry disability index (ODI) scores, neurological function, back and leg pain. All these measurements indicated an overall 81% clinical success and the study had a complication rate of just 9%[41]. Several other studies of various sizes have produced similar results indicating high clinical success rates ranging from 71%–100%[21,23,28,91–97] (Table 2).

Degenerative Lumbar Scoliosis

Degenerative lumbar scoliosis (DLS) is a deformity occurring after skeletal maturation causing abnormal spinal curvature and surgical correction is considered challenging[98,99]. Benefits of supporting the anterior column of the spine include increased stability, better fusion rates and restoration of normal lumbar lordosis[100–102]. ALIF is considered a reliable option because it allows for thorough release of contracted tissue and osteophytes, complete discectomy and distraction of the intervertebral space and placement of a larger interbody fusion device[103] (Fig. 5). All these factors contribute to strong anterior structural support. Moreover, an anterior approach gives increased attention to the sagittal plane enhancing segmental stability and yielding better long-term results with low complication rates compared to posterior and transforaminal interbody fusions[104]. The literature shows that when supplemented with posterior instrumentation, ALIF may be a reliable surgical option because it provides anterior structural support, corrects deformity and restores lordosis[103,105].

Pateder *et al*. had the largest study in the literature where 75 patients were retrospectively analyzed after receiving ALIF surgery with pedicle screw fixation for DLS. Due to the anterior thoracoabdominal approach with manipulation of major vessels and additional posterior approach, the complication rate was 24% with same day operation and 45% in anterior-posterior staged surgery. The correction of deformity was high

TABLE 3 Summary of clinical studies with degenerative scoliosis as the indication for ALIF[49,103]

Author	Study type	Surgery	Number of patients	Fusion rates (%)	Serious complication rate (%)	Comments
Crandell and Revella, 2009	Prospective, nonrandomized consecutive single surgeon series	ALIF + Posterior instrumentation	20	80	40	Average ODI and VAS scores improved
Pateder *et al*., 2007	Retrospective study.	ALIF + posterior instrumentation	75	88	24–45	Same day operation had lower complication to staged surgery.

ALIF, anterior lumbar interbody fusion; ODI, Oswestry disability index; VAS, visual analog scale.

and clinical outcomes correlated with the fusion rate which was 88%[49]. Crandall and Revella retrospectively studied 20 cases of DLS patients with similar results[103] (Table 3).

Pseudoarthrosis

Pseudoarthrosis occurs when there is a failure of union in a previous spinal fusion and in many cases, revision surgery is considered inappropriate. However, in cases of chronic pain non-responsive to conservative management, surgical intervention is necessary[106–108]. There are four types of pseudoarthrosis as described by Heggeness and Esses: atrophic, transverse, shingle, and complex[109]. The most common form is transverse where there is remodeled bone but horizontal discontinuity[108]. The pain is partly attributed to the sclerotic bone adjacent to fibrous soft tissue accompanied by microfractures of cancellous bone and motion of the segment[110]. Diagnosis of pseudoarthrosis is difficult and requires a significant amount of time after the fusion. Bony union is defined as absence of motion between the previously mobile segments due to bridging of bony trabeculae and this is difficult to assess[108].

Once conservative measures are unsuccessful and a surgical option is preferred, the aims for achieving fusion include correcting technical errors, better graft material, enhancing the biological environment for fusion and improving the biomechanical environment[106,107]. ALIF is a revision surgery option indicated mostly when other approaches produced the failed fusion[108,111]. If ALIF is used as the salvage procedure for a previous anterior approach, it is crucial to dissect through virgin tissue and review previous operations to see which segmental vessels were ligated[112]. High fusion rates can be achieved because of high bony surface area in the anterior column, excellent vascularity of well exposed end plates, cancellous bone and compression loading of the grafts[108]. The best outcomes are achieved with supplementary posterior instrumentation as it provides the maximum stability[108] (Fig. 6).

The literature shows that ALIF has been performed to correct previous failed fusions, particularly from posterior approaches. However, the overall number of cases where ALIF has been indicated for pseudoarthrosis is low. The majority of studies in the literature using other approaches show that it is costly and difficult to perform a revision procedure for pseudoarthrosis and the outcomes vary widely[108]. Butterman *et al*. had a study in the literature where 38 patients were retrospectively analyzed after receiving ALIF and posterolateral fusion surgery for pseudoarthrosis. The fusion rate was 95% and the surgical complications rate was high (64%)[113].

Adjacent Segment Disease (ASD)

ASD occurs when there is degeneration to the vertebral disc directly above or below a fused spinal segment because of hypermobility and increased biomechanical stress and is considered a long-term complication of spinal arthrodesis[114,115]. Common findings include disc degeneration, disc herniation, pseudoarthrosis, faced degeneration, hypertrophic changes, lateral recess stenosis, spinal stenosis, foraminal stenosis and

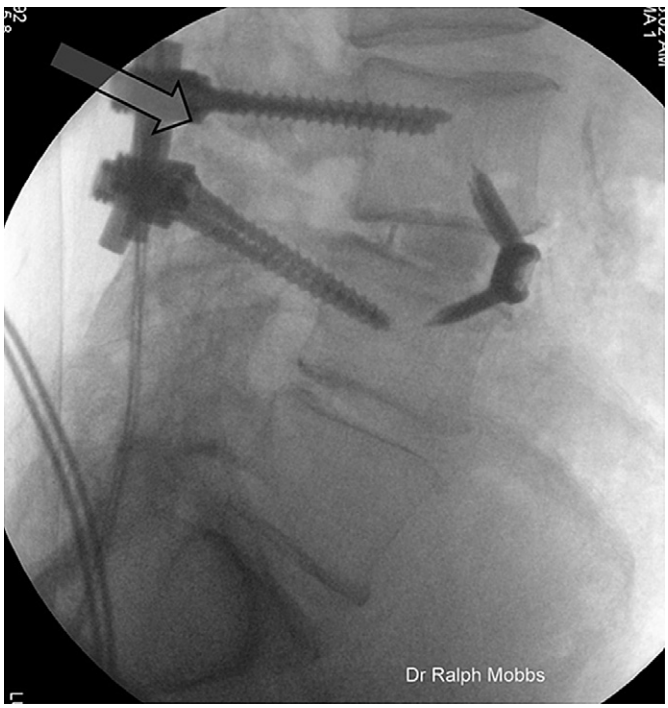

Fig. 6 Lateral X-ray lumbar spine demonstrating an $L_{3,4}$ ALIF, performed 18 months following posterior fusion with non-union of the posterior elements (see arrow).

instability[116]. Surgery is uncommon but is considered when medical treatment fails to adequately manage back pain and radicular leg pain[116]. Biomechanical studies show that the previous lumbar fusion often increases motion and intradiscal pressure leading to ASD[114]. ALIF is considered a revision surgery in this context to achieve sagittal or coronal realignment, normal lordotic curvature and relieve pain[117]. There is a lack of clinical studies that use ALIF as the stand-alone treatment option for ASD[85].

Other Indications

The rationale of ALIF surgery demonstrates that it is a viable option in cases of instability of the lumbar spine and cases of chronic lower back pain. Hence, there are several other potential indications in the literature including Pott's disease of the spine, fracture, dislocation, trauma causing internal disc disruption, recurrent lumbar disc herniation, post-discectomy collapse, coronal and/or sagittal plane deformity, instability after laminectomy or posterior decompression, spinal osteotomy, kyphosis and after spinal tumor resection[1,22,23,30,31,118]. However, the data on these specific indications was minimal based on current literature reviews.

Conclusion

Overall, it is evident that spinal fusions have evolved dramatically over the past century and ALIF has experienced several advances particularly in the last decade. The rationale underlying ALIF surgery is theoretically sound and it appears to be a viable option in several degenerative pathologies of the lumbar spine. Indications vary depending on the surgeon and the patient but generally cases of instability, chronic pain and deformity of the lumbar spine are potential candidates for ALIF. While independent studies have been conducted for some specific indications, there is yet to be a clinical study relating operative outcomes against the variety of different indications for ALIF surgery.

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