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ORIGINAL ARTICLE

The role of minimally invasive lateral lumbar interbody fusion in sagittal balance correction and spinal deformity

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Abstract
Purpose The recent proliferation of minimally invasive lateral lumbar interbody fusion (LLIF) techniques has drawn attention to potential for these techniques to control or correct sagittal misalignment in adult spinal deformity. We systemically reviewed published studies related to LLIF use in adult spinal deformity treatment with emphasis on radiographic assessment of sagittal balance.
Methods A literature review was conducted to examine studies focusing on sagittal balance restoration in adult degenerative scoliosis with the LLIF approach.
Results Fourteen publications, 12 retrospective and 2 prospective, reported data regarding lumbar lordosis correction (1,266 levels in 476 patients) but only two measured global sagittal alignment.
Conclusion LLIF appears to be especially effective when the lumbar lordosis and sagittal balance correction goals are less than 10° and 5 cm, respectively. However, the review demonstrated a lack of consistent reporting on sagittal balance restoration with the MIS LLIF techniques.

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Keywords Lateral interbody fusion · LLIF · Degenerative lumbar scoliosis · Intervertebral disk degeneration · Sagittal balance · Lumbar lordosis correction

Introduction

In recent years, sagittal balance has become a much debated topic. This is due in large part to its influence on patient satisfaction and clinical outcomes, as shown in various biomechanical and clinical studies on degenerative and idiopathic scoliosis [1, 2].

In the same way, the development and diffusion of the new minimally invasive anterior techniques, such as the LLIF techniques [3], reveal their ability to control and correct sagittal misalignment. Lateral approaches (such as XLIF and DLIF) provide reduced risks related to the anterior direct approaches as anesthetic complications, visceral damage, large vessels bleeding and sexual dysfunctions and should permit an early patient mobilization [4–8]. Nevertheless, the ability to correct global misalignment is not clear.

Traditional techniques, used to correct sagittal imbalance, include the shortening of posterior column as the Smith-Petersen or the pedicle subtraction osteotomies and the anterior–posterior spine-shortening procedure, but they are associated with high intraoperative risk for bleeding and neurological damage [9–12].

Today minimally invasive LLIF techniques are recognized as able to decompress neural structures by indirect distraction [13]; however, no clear data are present in the literature about its ability to correct sagittal alignment. The aim of this work is to review the pertinent literature as it pertains to the role of the LLIF techniques in correcting sagittal balance.

Table 1 The main characteristics of the studies, number of patients and surgeries applied

PAPER	Study	PZ	Levels	Anterior surgery/cage	Posterior surgery	Coronal segmental Cobb		Coronal regional Cobb		% of increase	Coronal plain alignment (mm)		Sagittal segmental Cobb		Regional lumbar lordosis		Δ	Sagittal alignment	
						Pre	Post	Pre	Post		Pre	Post	Pre	Post	Pre	Post		Pre	Post
Dakwar 2010 [14]	R	25	76	XLIF	15 LP, 7 oPS, 1(LP + oPS), 2 standalone	NR	NR	20.7°	6.2°	70.1	NR	NR	NR	NR	NR	NR	NR	restored in 16 out 25 PZ	
Tormenti 2010 [15]	R	8	23	XLIF	8 oPS	NR	NR	38.5°	10°	74.0	NR	NR	NR	NR	47.3°	40.4°	−6.9°	NR	NR
Wang 2010 [16]	R	23	85	XLIF	23 pPS	NR	NR	31.4°	11.5°	63.4	NR	NR	NR	NR	37.4°	45.5°	8.1°	NR	NR
Acosta 2011 [17]	R	36	66	XLIF	35 oPS 1 standalone	4.5°	1.5°	7.6°	3.6°	52.6	19.1	12.5	5.3°	8.2°	42.1°	46.2°	4.1°	41.5 mm	42.4 mm
Marchi 2011 [18]	R	8	17	XLIF/6(20°L + 20°L)–1(20°L + 30°L)–1(20°L + 20°L + 30°L)	4 oPS 4 standalone	NR	NR	NR	NR	NR	NR	NR	2.3°	27.1°	14.9°	40.8°	25.9°	NR	NR
Sharma 2011 [19]	R	43	87	XLIF/10°L	33 oPS, 10 standalone	5.2° t	1.5°	10.0°	6.8°	32.0	NR	NR	5.4°	8.2°	47.8°	49.3°	1.5°	NR	NR
Le 2013 [20]	R	28 nl	50	XLIF/10°L	2 lateral screws included in the cage	NR	NR	NR	NR	NR	NR	NR	13.0°	15.3°	56.4°	57.3°	0.9°	NR	NR
		7 hl		XLIF/10°L	2 lateral screws included in the cage	NR	NR	NR	NR	NR	NR	NR	2.3°	5.9°	37.7°	39.4°	1.7°	NR	NR
Castro 2013 [21]	R	35	107	XLIF	35 standalone	NR	NR	21°	12°	42.9	NR	NR	NR	NR	32°	41°	9°	NR	NR
Caputo 2013 [22]	R	30	127	XLIF	30 pPS + 11ALIF(L5-S1)	NR	NR	20.2°	5.8°	71.3	NR	NR	9.2°	9.7°	43.5°	48.5°	5°	NR	NR
Johnson 2013 [23]	R	30	41	XLIF	24 standalone, 3 PS, 3 interspinous device	NR	NR	13.0°	7.1°	45.4	NR	NR	3.0° to	6.6°	42.8°	44.4°	1.6°	NR	NR
Phillips 2013 [24]	P	107 (36 hl)	322	XLIF	80 PS (60 %o + 40 %p), 20 standalone, 7 anterolateral fixation	NR	NR	20.9°	15.2°	27.3	NR	NR	NR	NR	26.7° (1)	47.6° (1)	19.9°	NR	NR
Khajavi 2014 [25]	P	21	70	XLIF/0°	13 standalone, 8pPS	NR	NR	27.7°	16.6°	40.1	NR	NR	11.6°	17.2°	31.8°	44.0°	12.2°	NR	NR
Malham 2014 [26]	P	20	24	XLIF/10°L	20 standalone	NR	NR	NR	NR	NR	NR	NR	7.9°	9.4°	48.8°	55.2°	6.4°	NR	NR
		19	30	XLIF/10°L	19 PS	NR	NR	NR	NR	NR	NR	NR	7.6°	10.5°	51.1°	45.8°	−5.3°	NR	NR
Manwaring 2014 [27]	R	27	126	XLIF 10°L + 30°L at ALL-level	27 ALLr, 27 pPS, 11 TLIF-L5-S1, 4 ALIF (L5-S1)	NR	NR	24.8°	9.0°	65.80	NR	NR	NR	NR	36.5°	53.4°	16.9°	83 mm	37 mm
		9	15	XLIF/10°L	9 pPS	NR	NR	28.9°	12.4°	57.10	NR	NR	NR	NR	43.7°	45.9°	2.2°	23 mm	38 mm
TOT		476	1266							Wa: 50.5									

(1), value for hypolordotic patients

P prospective, *R* retrospective, *nl* normolordosis, *hl* hypolordosis, *L* lordotic, *LP* lateral plating, *oPS* open posterior screws, *pPs* percutaneous posterior screws, *ALIF* anterior lumbar interbody fusion, *ALLr* anterior longitudinal ligament release, *pre* preoperatory, *post* post-operatory, *wa* weighted average

Materials and methods

The electronic research was conducted in April 2014 in the major healthcare databases comprising Medline, Embase, Scopus and Cochrane library to include papers published between 2001 and 2014.

The following keywords were adopted: "minimally invasive anterior approach lumbar interbody fusion", "minimally invasive lateral approach lumbar interbody fusion", "XLIF", "minimally invasive spine surgery" and "sagittal balance".

Inclusion criteria were: studies in the English language reporting data about controlling lumbar lordosis and sagittal balance by LLIF.

Exclusion criteria were: papers not reporting exhaustive data regarding sagittal alignment, case reports, cadaveric or biomechanical studies.

After the first electronic research and the selection based on abstract review, the successive phase consisted of reading all selected papers and relative references to do final selection.

Results

The electronic research allowed identification of 177 papers. After reading titles and abstracts, 20 papers underwent full review and references screening.

At the end of the process 14 papers were considered suitable for reviewing proposal (Table 1). Because of the absence of standardized populations, surgeries and outcome measures, and because of lack of a sufficient number of prospective studies, a meta-analysis was considered not possible, coming along with a systematic review.

The selected papers were 12 retrospective and 2 prospective studies, including a total 476 patients and 1,266 levels where LLIF played a role in the overall surgical plan. In about the 28 % LLIF was performed standalone (Fig. 1). In the remaining part, a further stabilization was applied successively, in the same surgery, or in the following days. Posterior stabilization with pedicle screws was adopted in about the 61 % of the patients and in the 45 % of them the screws were inserted with percutaneous technique (this percentage consistently increases considerably in the last years). Posterior instrumentation had the intent of stabilizing the anteriorly obtained correction.

Considering the studies reporting data about coronal plane correction, lumbar curve improved of 50.5 % of the original value (weighted average calculated on 323 patients, Table 1).

Even though most of the authors declare that restoring sagittal balance is one of the outcomes, only the papers of

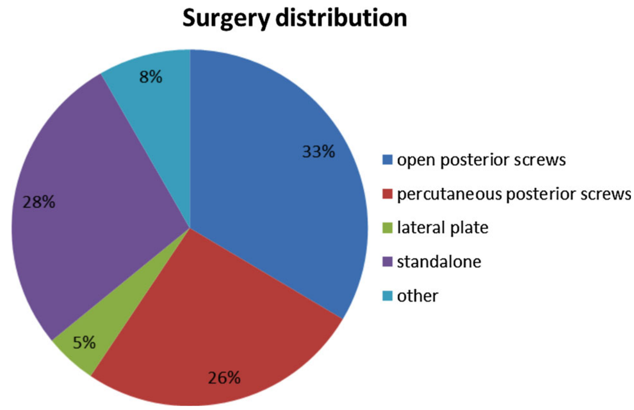

Fig. 1 Surgery distribution; posterior screws are applied in most of the cases to stabilize the correction reached by anterior approach

Manwaring et al. and Acosta et al. furnished quantitative data; Acosta reported no variation, while Manwaring reported an improvement of 46 mm of the sagittal balance considering patients with hypolordosis where anterior longitudinal ligament release was also performed [17, 27].

Dakwar et al. [14] declared they had restored sagittal balance in 16 out 25 patients without giving quantitative data.

Data regarding lumbar lordosis variation is available for every study: the weighted average variation is 6.5° above 380 patients (the study of Phillips et al. [24], presents 107 patients and reports lumbar lordosis variation of a hypolordotic subgroup of 36 patients). Nevertheless, if the studies are divided into two groups based on if the average preoperative lordosis is lesser or higher than 40°, the weighted average variation results of 13.7° and 1.3° for "hypolordotic group" (157 patients) and "normolordotic group" (223 patients), respectively.

Just two authors, Marchi and Manwaring, specified the use of 20° and 30° cages and, with Phillips, are the only authors referring a lordosis correction higher than 13.7° [18, 24, 27].

Discussion

The origin of degenerative lumbar scoliosis is closely related to an asymmetric collapse of the lumbar disks and to the onset of osteoarthritis with loss of normal joint matches [28].

This asymmetric collapse can cause two main categories of sagittal misalignment with different related problems: type 1 and type 2. The patient affected by a type 1 imbalance has a segmental or regional problem, but the global spinal alignment is still maintained; the patient affected by a type 2 imbalance has a more severe problem with global spine impairment [29].

Several methods were proposed in the literature to evaluate the sagittal balance. The C7 plumb line usage is probably the most used; correct global spine alignment is present when a plumb line, drawn from the center of the C7 vertebral body, passes between 25 and 55 mm anteriorly to the posterior-superior aspect of S1. In that case sagittal balance is defined "neutral". That line, named sagittal vertical axis, falls posteriorly or more anteriorly in negative and positive sagittal balance, respectively [30, 31].

This system ignores the positioning of the head and of the cervical spine, and therefore, other methods were recently proposed, such as the cranio-cervical alignment [32]. Nevertheless, the traditional definition is considered for the aim of presenting review.

The disequilibrium of the sagittal balance is probably one of the most important causes for persisting low-back pain after surgery, adjacent level syndrome and hardware failure [33–35]; it is also responsible for further consequences on underling segments and joints; several studies are available in the literature concerning not only spine balance, but the relation to the pelvis as well. Indeed, to compensate for decreased lumbar lordosis, the pelvis creates retroversion with decrease of sacral slope [23, 36].

The first therapeutic approach is usually conservative but, unfortunately, surgery sometimes becomes necessary. When the misalignment is minimal, it is possible to correct it with posterior screws stabilization; otherwise more complex operations and important osteotomies are required. Nevertheless, these techniques present a high operatory risk due to anesthesia related problems and blood loss, a high risk of cord and nerve roots damage, and also of pseudoarthrosis which can reach 24 % of cases after long fusion surgery in adults [37].

The frequent comorbidity, present in this class of patients, makes minimally invasive techniques the more advisable approach. The safety profile of LLIF is already attested and presenting review showing the ability of LLIF to restore sagittal balance is a challenging problem in the literature. Unfortunately, most of the studies are not conclusive and are particularly focused just in lumbar lordosis with a satellite interest in the consequences on the superior segments.

Dakwar et al. [14], in 2010, were probably the first who valued the achievement of a sagittal balance after LLIF. Using the XLIF technique, they reported data about 25 patients with adult degenerative scoliosis referring that sagittal balance was obtained in 16 out 25 cases; nevertheless they do not report preoperative status and sufficient data about methods used for outcomes measures.

Also Acosta et al. [17] consider in their investigation global alignment; they reported a good correction of coronal parameter (in 8 patients with lumbar scoliosis the preoperative coronal Cobb angle of 21.4° was surgically reduced to 9.7°) and a sufficient control of the sagittal imbalance, maintained in normal range also after surgery.

Manwaring et al. [27], in a recent paper, demonstrated a good control of sagittal balance in a group of 9 patients with a preoperatory neutral balance and an even better correction in a second group of 27 patients where the vertebral axis offset was improved from 83 to 37 mm.

More analyzed are the results obtained in restoring lumbar lordosis. Even if some authors hypothesized the absence of control of lordosis as Tormenti et al. [15], the availability of different lordotic cages (from neutral to 30° of lordosis) allowed also correcting lordosis; presenting review shows an average lordosis correction of 13.7° in those patients with a preoperative value inferior to 40°.

Wang et al. [16], in 2010, published their experience above 23 patients affected by degenerative lumbar scoliosis greater than 20° or sagittal imbalance. They treated them with LLIF followed by percutaneous transpedicular screws performed on the same day reporting a scoliosis redaction from an average of 31.4–11.5° and a restoring lordosis from 37.4° to 45.5°.

The study of Marchi et al. [18], even if performed just on 8 patients, reported important information about lordosis correction. In their population, the average lumbar lordosis changed from 14.9° to 40.8° with an increased focal lordosis from 2.3° to 27.1°. These results were reached with the insertion of 20° and 30° lordotic cages. They pointed out the attention on the importance of respect the endplate during the cage insertion; they found that, in case of its violation, only an average of the 23 % of the cage slope was reported on the focal lordosis, otherwise this value could reach also the 58 % in case of correct insertion allowing the 20° lordotic cage to add 10° to the regional lordosis and the 30° lordotic cage to add 15°.

Actually, the insertion of the 30° lordotic cage can be very difficult in case of a very narrow intervertebral space so, in 2012, Deukmedjian et al. [38] proposed the anterior longitudinal ligament release to make the cage insertion easier and reduce the risk of endplate damage.

They reached an average segmental sagittal correction of 17° (more than the half of the value of the 30° cage), an average lordosis correction of 24° and a change of sagittal alignment from 9 to 4.1 cm. After one year, in a second paper, they proposed their protocol treatment suggesting to apply XLIF and percutaneous screws fixation in those cases with coronal Cobb angle <30° and sagittal misalignment <5 cm; in those case with coronal Cobb angle >30° and an alteration of the sagittal balance from 5 to 9, they suggested the anterior longitudinal ligament release and eventually facetectomies; also osteotomies in more severe cases [39].

Presenting review evidenced as in 28 % of the case LLIF was performed standalone. Even if posterior screws were not used use to further correct the alignment, they made stabilization more rigid so that they could be helpful to stabilizing results in time, moreover, when more levels are treated and the needed correction is important, as suggested by Phillips et al. [24] in 2013 in an important multicenter prospective study. They reported their experience above a total population of 107 treated patients where 36 had a reduced lumbar lordosis with an average value of 26.7°. In this population, LLIF was able to restore normal values with an improvement of 78.3 %. In a recent study, Khajavi et al. [25] suggested the importance of posterior stabilization to assure better results but unfortunately, because of the low number of patients, their results were not significant. Nevertheless, they reported an increase of segmental and regional lordosis of 48 and 39 %, respectively, and an increase of disk and foraminal height of 102 % and 32 %, respectively. Malham et al. [26], in a recent publishing paper, proposed a flowchart helping surgeons to decide if to perform standalone LLIF or to add a posterior stabilization as well. Osteoporosis, vertebral instability, more than two levels and facet arthropathy are possible suggestions to add posterior stabilization too. Nevertheless, randomized comparative studies are advocated to clarify this topic.

The effect of LLIF on lordosis depends on several factors such as the lordotic cage value, the respect of the endplates, the possible osteoporosis. The effect on the vertebral axis and sagittal balance is influenced by the level of insertion but also by the height of the patients. The more distal the level involved and the higher the patient, the greater the chance that there will be the backward effect on the vertebral axis.

Therefore, these factors have to be taken into account when deciding to utilize the LLIF approach. It appears to be indicated when the needed lumbar lordosis and sagittal balance correction are lower than 10° and 5 cm, respectively.

It is likely that future studies will continue to define the role of LLIF in adult spinal deformity. Specifically, the role of sectioning the anterior longitudinal ligament and the role of hyperlordotic interbody cages will be better elucidated. It is probable that open posterior osteotomies will continue to be the gold standard in sagittal balance correction, until consistent data emerge from the MIS literature proving that MIS lateral approaches alone can address this issue.

Conflict of interest None.

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