Interdisciplinary Neurosurgery 18 (2019) 100523

Contents lists available at ScienceDirect

Interdisciplinary Neurosurgery

journal homepage: www.elsevier.com/locate/inat

Neuroanatomical Studies

Morphometric analysis of 900 lumbar intervertebral discs: Anterior and posterior height analysis and their ratio

Franz Jooji Onishi (MD)*, Manoel Antonio de Paiva Neto (PhD), Sérgio Cavalheiro (PhD), Ricardo Silva Centeno (PhD)

Department of Neurology and Neurosurgery, Federal University of Sao Paulo, Brazil

ARTICLE INFO

Keywords:
Intervertebral disc
Spinal curvatures
Spinal fusion
Sagittal balance

ABSTRACT

Objective: To evaluate the height of normal intervertebral discs and describe their differences after analyzing anterior and posterior height.

Methods: Retrospective study based on analysis of analysis of lumbar spine magnetic resonance imaging. We included male and female patients who underwent lumbar spine resonance, most of them for investigation of low back pain. Patients with previous surgeries, advanced degenerative disc disease, suspected infection, deformities were excluded from the study.

Results: 300 patients had their images analyzed for the anterior and posterior height of the L3-L4, L4-L5 and L5-S1 discs, totaling 900 intervertebral discs. The mean age of the patients was 46,2 ± 15,1 years. The mean anterior disc height of L3-L4 was 9.30 mm, L4-L5 10.94 mm and L5-S1 12.41 mm. About 7% of the patients have a L3-L4 anterior height < 7 mm, which is usually the smallest available cage height. The ratio obtained by dividing the anterior height by the posterior height was 1,47 for L3-L4; 1,62 for L4-L5 and 2,00 for L5-S1. It means that the posterior disc height is half the anterior disc height for the L5-S1, making this segment the most important in the formation of lumbar lordosis. The anterior disc height showed progressive decrease with aging, with Pearson correlation value of −0,36 for L3-L4, −0,96 ($p < 0,05$) for L4-L5. The L5-S1 anterior disc height has not change with aging $r = 0,005$ ($p > 0,05$).

Conclusions: L3 to L5 discs present greater anterior height than posterior and this difference tends to decrease with aging. The L5-S1 disc is that most contributes for lumbar lordosis, followed by L4-L5. Populations with lower average height should have their disc dimensions carefully studied during surgical planning, especially in L3-L4 segment.

1. Introduction

The prevalence of degenerative diseases of the lumbar spine increases with age. Such aging process leads to changes in the height of the intervertebral disc and its contents, and although degenerated discs are not necessarily painful, pain (i.e. low back pain) affects a large number of patients. As a matter of fact, low back pain in one of the most frequent musculoskeletal pains in humans [1].

Faced with an exponential increase in surgeries related to the intervertebral disc, one of the major difficulties in clinical practice is to distinguish degenerative changes from segments adjacent to a lumbar fusion surgery from the natural aging process of the intervertebral disc - such differences may be impossible to discriminate based on radiological parameters alone [2–4].

Post-surgical chronic pain and walking difficulties have been related in association with changes in lumbar curvature and overall sagittal alignment of the spine. Rectification of the lumbar spine has been extensively studied and there is a strong correlation between poor surgical results with surgical planning leading to loss of lumbar lordosis [5,6].

The ideal lumbar lordosis consists in its main component location between L4 and S1 (67% of total lordosis), and 97% of it between the L2 and S1 segments [7].

Lumbar spine fusion surgeries are among the most widely performed procedures in the spine and the intervertebral discs are currently the target of several surgical techniques. The knowledge of their anatomy and dimensions may lead to better surgical results.

Abbreviations list: A, anterior; P, posterior; M, male; F, female

* Corresponding author at: Federal University of Sao Paulo, Rua Napoleão de Barros 715, 6o Andar, Brazil.
E-mail address: neurocirurgia@gmail.com (F.J. Onishi).

https://doi.org/10.1016/j.inat.2019.100523
Received 2 March 2019; Received in revised form 6 May 2019; Accepted 29 June 2019

2. Objectives

The present study aims to evaluate the lumbar intervertebral discs that are most frequently associated with degenerative diseases (L3-L4, L4-L5 and L5-S1), in their anterior (A) and posterior (P) heights and the A/P ratio, obtained dividing the anterior height by the posterior.

3. Patients and methods

Patients who underwent magnetic resonance imaging of the lumbar spine were considered eligible for the study. The images were obtained in high definition devices in a closed magnetic field of 1.5 or 3.0 Tesla.

We selected 300 consecutive patients - 150 male and 150 female patients between 18 and 75 years. Clinical data on ethnicity, age and gender were obtained by means of an electronic patient record. 95% of the MRI were done to investigate low back pain. Other reasons presented were demyelinating disease investigation, investigation of chronic pelvic pain, complementary investigation of hip disease.

Patients with previous surgeries of the spine, deformities such as congenital/spondylolisthesis/scoliosis/kyphosis/anomalies were excluded from the study. Suspicious images of neoplasia or infectious process were also excluded. Patients with mild degenerative changes of the lumbar spine compatible with aging were included.

An independent radiologist also evaluated the patients' MRI images and the data were extracted only when there was concordance of the criteria mentioned above.

The images were analyzed in a T2-weighted midsagittal (or near-median) slice and their measurements were performed using the SYNAPSE PACS program tools (Fujifilm USA). To be included, patients would have MRI analyzed by the investigator and the radiologist. Both would have to agree that the intervertebral discs were healthy or had tenuous changes consistent with the age of patients (Fig. 1).

We calculate the mean height of the disks of each segment, by simple arithmetic mean between A and P - obtained by the following formula - mean disc height = (A + P)/2. We also calculated the anterior/posterior ratio, dividing A/P. The data were analyzed using the IBM-SPSS 22 program. The analysis of multiple comparisons was performed among the different groups using the ANOVA test. Significant values of $p < 0.05$ were considered for statistical purposes.

Table 1
Study population characteristics.

Study population characteristics	
n	300
Total number of discs studied	900
Female, n (%)	150 (50%)
Male, n (%)	150 (50%)
Ethnicity	
White, n (%)	100 (33,3%)
Black, n (%)	26 (8,6%)
Asian, n (%)	7 (2,3%)
Brown, n (%)	155 (51,6%)
Others, n (%)	12 (4%)
Mean age (range)	46,2 yo (18–75)

4. Results

We analyzed the lumbar disc height of 300 patients (M = 150, 50%; F = 150; 50%) with a total of 900 discs. The general characteristics of the population are described in Table 1.

The ethnicity analysis showed the following distribution: 155 (51.6%) brown, 100 (33%) whites, 26 (8.6%) blacks, 7 (2,3%) yellows and 12 (4%) from other ethnicities. No differences were found of mean disc height between the different races as shown in Table 2.

We found a greater difference between the anterior and posterior heights in the L5-S1 and L4-L5 segments - being the main segments responsible for lumbar lordosis formation. It should be noted that despite the higher anterior height, the posterior height of the L5-S1 segment was smaller than the L4-L5 segment, confirming that this is the main segment responsible for lumbar lordosis (Table 3).

Women are usually shorter than men. This difference is expected also in disc height, then we seek to find the differences in disc height according to the patient gender.

The mean height of the disks in the male gender was higher than in the female gender, but statistical difference was demonstrated only in the L4-L5 segment. Anterior disc height was different between female and male patients, only when comparing the anterior disc height of L3-L4 and L4-L5 segments.

The anterior minus posterior disc height difference and the A/P ratio did not differ between men and women as seen in Table 4.

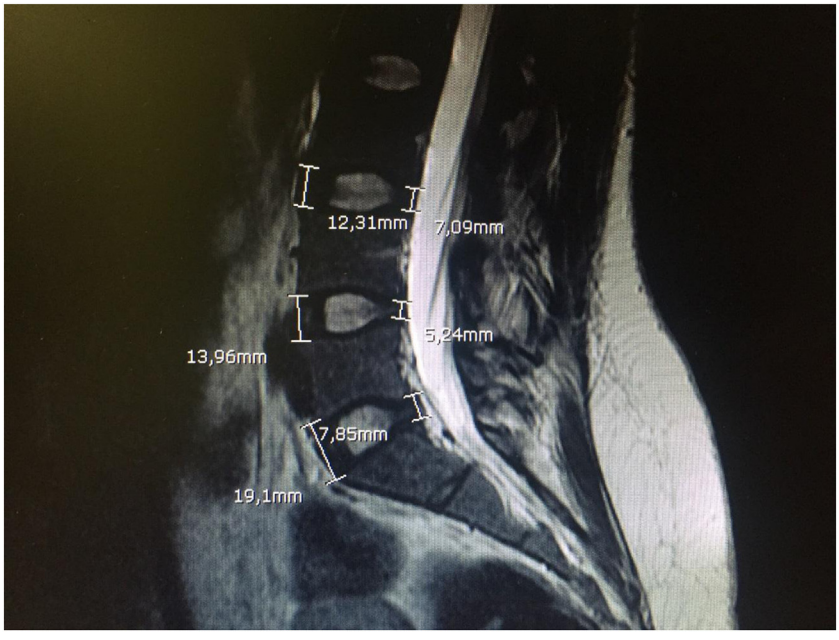

Fig. 1. Measurement of anterior and posterior height of the studied discs.

Table 2
Analysis by ethnicity - mean height of the discs (A + P)/2 in mm.

	L3-L4	L4-L5	L5-S1
Brown (n = 155)	8,06	8,36	9,69
White (n = 100)	7,76	8,58	9,31
Black (n = 26)	7,76	7,64	9,20
Others (n = 12)	8,37	8,66	8,35
Asian (n = 7)	7,84	6,99	8,70

($p > 0,05$ one way ANOVA).

Table 3
Mean values of the morphological parameters of the studied segments.

	A height	P. height	Mean height (A + P)/2	Difference (A-P)	Ratio (A/P)
L3-L4	*9,30	65,036	**79,470	***28,045	****14,781
L4-L5	*10,94	69,517	83,978	40,004	16,227
L5-S1	*12,41	64,398	**94,498	***59,798	****20,096

*,**,***,**** Statistical difference between the groups, $p < 0,05$ ANOVA (Tukey).

Table 4
Analysis of the discs by gender (in mm).

	L3-L4	L4-L5	L5-S1
Mean height of the discs (A + P)/2			
Female (n = 150)	7,90	8,05*	9,38
Male (n = 150)	7,98	8,74*	9,51
Difference (M–F)	0,08	0,69	0,13
Anterior disc height of the discs			
Female (n = 150)	9,07**	10,67***	12,32
Male (n = 150)	9,53**	11,21***	12,51
Difference (M–F)	0,46	0,54	0,19
Anterior and posterior heights difference (A-P)			
Male (n = 150)	3,1	3,9	5,43
Female (n = 150)	2,71	3,61	5,14
Anterior and posterior heights ratio (A/P)			
Male (n = 150)	1,48	1,63	2,02
Female (n = 150)	1,47	1,61	1,99

*, **, ***statistical significance ($p < 0,05$ *t*-test).

The anterior disc height is progressively greater in the caudal direction, and the anterior heights of the studied lumbar discs are statistically different between them. L3-L4 had the lowest (9,3 mm) anterior measurement and L5-S1 had the highest (12,4 mm) anterior measurement (Fig. 2).

The difference between anterior and posterior disc height (A-P) is also increasing in caudal direction, with L5-S1 appearing more wedge shaped (Fig. 3).

We observed a large difference in the height of the L3-L4, L4-L5 and L5-S1 discs between the measurements of the anterior and posterior heights, mainly noticed in the segment L5-S1, being the mean difference of 5.1 mm in the female gender and 5.42 mm in the male gender. This finding corroborates findings from other studies that the main contributor to the maintenance of lumbar lordosis is the L5-S1 segment, followed by the L4-L5 segment.

The role of aging in loss of lordosis was noted in our study. Analyzing the parameters age and anterior disc height, we performed the Pearson correlation index. The anterior disc height showed progressive decrease with aging, with Pearson correlation value of $-0,36$ for L3-L4, $-0,96$ ($p < 0,05$) for L4-L5. The L5-S1 anterior disc height has not change with aging $r = 0,005$ ($p > 0,05$).

5. Discussion

Knowing the height of disk space is mandatory for proper selection of intervertebral devices (cages), and it is known that the most affected by degenerative diseases are the discs L5-S1, L4-L5, followed by the L3-L4.

Some different models that describe the degenerative lumbar disc disease have been studied and developed. The classification of Pfirrmann [8] is currently one of the most used, performed from the analysis of MRI and four parameters - disc structure, distinction between nucleus and annulus, disc intensity and height. According to these criteria the discs are classified in five categories. Nevertheless the Pfirrmann's classification does not consider losses of angulations or anterior-posterior height differences, consequently without any reference to the sagittal balance of the spine.

It is know that there is a tendency for the general population to become taller, due to factors still under study. Anthropometric analysis shows that Humans get taller as they reach adult years and consequently the intervertebral discs height are also raised.

A recent study [9] that included 18.6 million people worldwide, born between 1896 and 1996 in 200 countries showed a prevalence of taller men and women in European countries, with the average height of Dutch men being 1.82 m in 1994. Men born in the United States of America in the same year had an average height of 1,77 m. When we evaluated the Brazilians, we found mean height of 1.73 m for men and 1.63 m for women [9].

The analysis of absolute numbers has a probable bias of the influence of patient heights on the final result of the analysis of the morphometric data. Therefore we propose analyzing a ratio determined by the simple division of the anterior and posterior height of the analyzed discs, which can then have their extrapolated data, possibly for different populations of the population studied here. This ratio was also progressively increasing from segment L3-4 to segment L5-S1 with values of 1.47 for segment L3-L4, 1.62 for segment L4-L5 and 2.00 for segment L5-S1.

A practice widely used in surgeries is the indirect decompression, which involves the use of high cages in the previously reduced disc space, making laminectomy or other major decompressive procedures unnecessary [10].

On the other hand, excessive high cages, the surgical approaches to reach the disc space and excessive distraction are factors reported as causes of neurological complications and arthrodesis failure in some series, mainly due to cage subsidence. Some of the complications were permanent and require reoperations at the operated level and also in adjacent segments [11–17].

To avoid those complications, the ideal cage should have the same size (height) and respect the difference between anterior and posterior height of the average disc, taking into account the population you are treating, the level and gender of the patient.

As discussed before, the major developers and manufacturers of spinal prostheses are located in Europe or United States of America, and their population is taller than the majority of the other countries. We have a wide range of implant sizes, but most developers manufacture cages with an initial height of 7 mm or 8 mm.

We must pay attention during spinal surgeries, taking into account that there may be a discrepancy in size between the developed device and the population being treated, specifically in the L3-L4 segment, where > 22% of our studied patients have mean disc height < 7 mm. 21% of our studied group had mean L4-L5 disc space narrow than 7 mm and 11% of the patients had the L5-S1 mean disc space < 7 mm.

The analysis of absolute numbers has a probable bias of the influence of patient heights on the final result of the analysis of the morphometric data, so we proposed a new ratio parameter (A/P ratio) that could be extrapolated to different population, regardless of patient's height (Table 5).

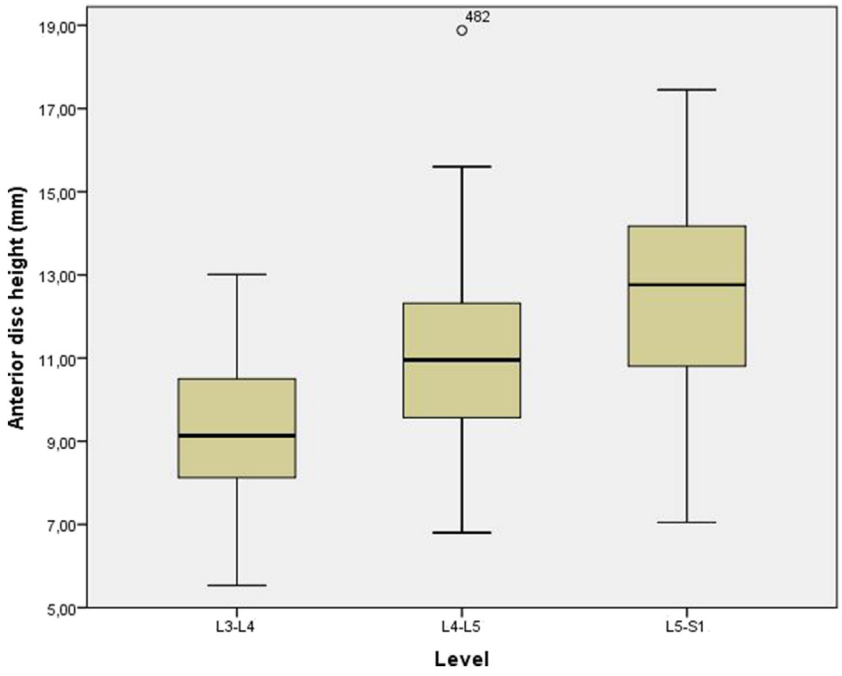

Fig. 2. Anterior disc height compared between the different segments.

6. Limitations of the study

The present study presents a limitation for analyzing the disc dimensions in a supine position determined by the acquisition of the MRI. Probably, in standing position, the dimensions of the discs would be different than the one we have found.

We cannot recover in our database the heights of all participants. However, by the criterion of analysis of our statistician there is a great chance of representation of our population, considering the n of 300 patients, with a statistical test attesting the normal distribution of the data studied.

Table 5
Some implant manufacturers and minimal TLIF height.
(Data taken directly from manufacturers' websites).

Manufacturer (country of origin)	Smallest TLIF cage heights available
Aesculap® (Germany)	7 mm
Depuy Synthes® (USA)	7 mm
SpineART® (Swiss)	8 mm
K2M® (USA)	7 mm
Alphatec® (USA)	7 mm
Zimmer® (USA)	7 mm
LDR® (France)	8 mm

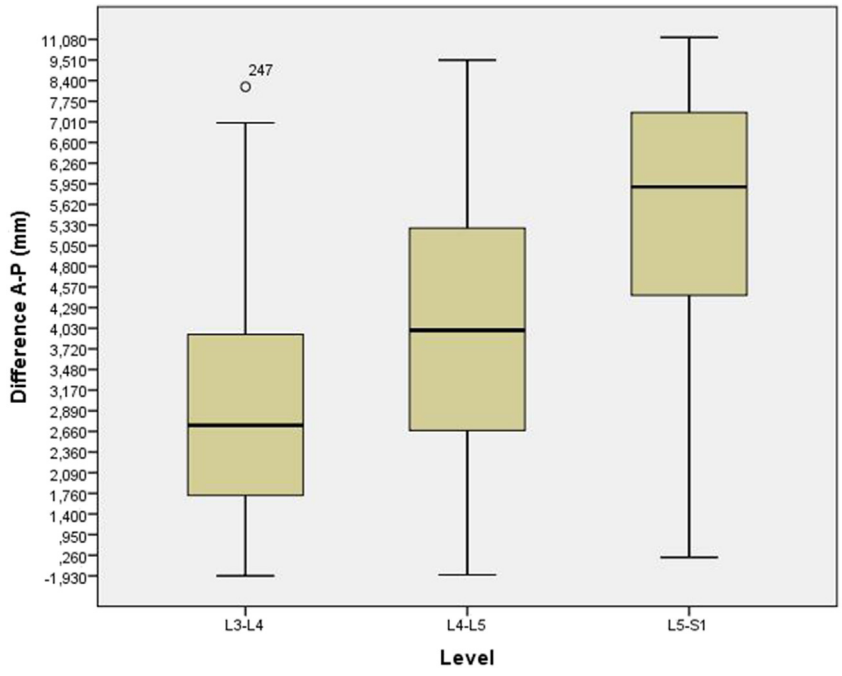

Fig. 3. Difference of anterior and posterior heights (A-P) in different segments.

7. Conclusions

The prostheses used in the lumbar interbody fusions must be individualized by segment, gender and population. We observed the need for elaboration of materials with customized height for populations of short stature, with attention to the L3-L4 segment especially in female patients.

The largest difference between A and P heights were found in the L5-S1 segment - what makes it the main segment for lumbar lordosis maintenance. This difference seems to be similar between male and female patients and was found in all the different races studied. We should prefer cages with lordosis angulation when planning a surgery, especially in segment L5-S1.

We propose the analysis of the A/P ratio in the surgical planning of lumbar diseases, with results of 1.47 for segment L3-L4, 1.62 for segment L4-L5 and 2.00 for segment L5-S1.

Declaration of Competing Interest

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors

References

[1] P. Suthar, R. Patel, C. Mehta, N. Patel, MRI evaluation of lumbar disc degenerative disease, J. Clin. Diagn. Res. 9 (4) (2015) TC04–9. Apr.

[2] S.D. Boden, D.O. Davis, T.S. Dina, N.J. Patronas, S.W. Wiesel, Abnormal magnetic-resonance scans of the lumbar spine in asymptomatic subjects: a prospective investigation, J. Bone Joint Surg. Am. 72 (1990) 403–408.

[3] W. Brinjikji, P.H. Luetmer, B. Comstock, et al., Systematic literature review of imaging features of spinal degeneration in asymptomatic populations, AJNR Am. J. Neuroradiol. 36 (2015) 811–816.

[4] M. Matsumoto, E. Okada, Y. Toyama, H. Fujiwara, S. Momoshima, T. Takahata, Tandem age-related lumbar and cervical intervertebral disc changes in asymptomatic subjects, Eur. Spine J. 22 (2013) 708–713.

[5] M. Eager, F. Jahangiri, A. Shimer, F. Shen, V. Arlet, Intraoperative neuromonitoring: lessons learned from 32 case events in 2095 spine cases, Evid. Based Spine Care J. 1 (2) (2010) 58–61. Aug.

[6] S.B. Lee, W.J. Cho, The effect of sling exercise on sagittal lumbosacral angle and intervertebral disc area of chronic low back pain patients, J. Exerc. Rehabil. 12 (5) (2016) 471–475 Oct 31.

[7] P. Roussouly, S. Gollogly, E. Berthonnaud, J. Dimnet, Classification of the normal variation in the sagittal alignment of the human lumbar spine and pelvis in the standing position, Spine 30 (2005) 346–353.

[8] C.W. Pfirrmann, A. Metzdorf, M. Zanetti, J. Hodler, N. Boos, Magnetic resonance classification of lumbar intervertebral disc degeneration, Spine (Phila Pa 1976) 26 (17) (2001) 1873–1878.

[9] NCD Risk Factor Collaboration (NCD-RisC), A century of trends in adult human height, Elife 5 (2016 Jul 26), https://doi.org/10.7554/eLife.13410 pii: e13410.

[10] L. Oliveira, L. Marchi, E. Coutinho, Pimenta L. A radiographic assessment of the ability of the extreme lateral interbody fusion procedure to indirectly decompress the neural elements, Spine (Phila Pa 1976) 35 (26 Suppl) (2010 Dec 15) S331–S337.

[11] N. Bocahut, E. Audureau, A. Poignard, J. Delambre, S. Queinnec, C.H. Flouzat Lachaniette, J. Allain, Incidence and impact of implant subsidence after stand-alone lateral lumbar interbody fusion, Orthop. Traumatol. Surg. Res. 104 (3) (2018) 405–410 May.

[12] T. Kaito, N. Hosono, T. Fuji, T. Makino, K. Yonenobu, Disc space distraction is a potent risk factor for adjacent disc disease after PLIF, Arch. Orthop. Trauma Surg. 131 (11) (2011) 1499–1507 Nov.

[13] A.T. Nixon, Z.A. Smith, C.D. Lawton, A.P. Wong, N.S. Dahdaleh, A. Koht, R.G. Fessler, Bilateral neurological deficits following unilateral minimally invasive TLIF: a review of four patients, Surg. Neurol. Int. 5 (Suppl. 7) (2014 Aug 28) S317–S324.

[14] P.J. Rao, K. Phan, G. Giang, M.M. Maharaj, S. Phan, R.J. Mobbs, Subsidence following anterior lumbar interbody fusion (ALIF): a prospective study, J. Spine Surg. 3 (2) (2017) 168–175 Jun.

[15] S.N. Salzmann, J. Shue, A.P. Hughes, Lateral lumbar interbody fusion-outcomes and complications, Curr. Rev. Musculoskelet. Med. 10 (4) (2017) 539–546, https://doi.org/10.1007/s12178-017-9444-1 Dec.

[16] F. Taher, A.P. Hughes, D.R. Lebl, A.A. Sama, M. Pumberger, A. Aichmair, R.C. Huang, F.P. Cammisa, F.P. Girardi, Contralateral motor deficits after lateral lumbar interbody fusion, Spine (Phila Pa 1976) 38 (22) (2013) 1959–1963 Oct 15.

[17] Z.J. Tempel, M.M. McDowell, D.M. Panczykowski, G.S. Gandhoke, D.K. Hamilton, D.O. Okonkwo, A.S. Kanter, Graft subsidence as a predictor of revision surgery following stand-alone lateral lumbar interbody fusion, J. Neurosurg. Spine 28 (1) (2018) 50–56 Jan.