Surg Radiol Anat (2011) 33:665–671
DOI 10.1007/s00276-011-0798-6

ORIGINAL ARTICLE

Safe working zones using the minimally invasive lateral retroperitoneal transpsoas approach: a morphometric study

Patrick Guérin · Ibrahim Obeid · Olivier Gille · Anouar Bourghli · Stéphane Luc · Vincent Pointillart · Jean Christophe Cursolle · Jean-Marc Vital

Received: 15 November 2010 / Accepted: 18 February 2011 / Published online: 8 March 2011

Abstract

Purpose The minimally invasive lateral retroperitoneal transpsoas approach is a recent technique developed for lumbar interbody fusion and discectomy. The proximity of the retroperitoneal vessels and ventral nerve roots to the surgical pathway increases the risk of injury to these anatomical structures. A precise knowledge of the regional anatomy of the lumbar plexus is required for safe passage through the psoas muscle. Preoperative examination of the axial MRI images will allow the surgeon to observe the neural structures at the operative levels and confirm that abdominal vessels do not obstruct the lateral disc space. The objective of this study was to determine the anatomic position of the ventral nerve roots and the retroperitoneal vessels in relation to the vertebral body in the degenerative spine and to delineate a safe working zone using magnetic resonance imaging (MRI).

Methods We retrospectively evaluated lumbar spine MRI in 78 patients (from L1–L2 to L4–L5). The total number of lumbar vertebrae measured was 304 levels. Sagittal MRI sections were used to measure disc height (anterior, middle, posterior). Axial MRI sections were used to measure the sagittal and transversal vertebral endplate diameters, the overlap between ventral nerve roots and the posterior border of the lower endplate of the vertebral body, and the overlap between the retroperitoneal vessels and the anterior border of the lower endplate of the vertebral body. The safe zone was subsequently calculated. It was defined as the relative lower endplate vertebral body sagittal diameter that is anterior to the nerve root and is posterior to the retroperitoneal vessels.

Results The safe working zone was 75.3% of the lower endplate of the vertebral body sagittal diameter at L1–L2, 59.5% at L2–L3, 51.9% at L3–L4 and 37.8% at L4–L5 levels. This area significantly decreases from L1–L2 to L4–L5 ($p < 0.05$). Compared with L1–L2, L2–L3 levels, the more anterior position of the nerve root and the more posterior position of the retroperitoneal vessels at the L4–L5 level causes a significant reduction of this area. Compared with the L3–L4 level, we observed that the safe zone decrease was simply secondary to the more anterior position of the nerve roots at the L4–L5 level.

Conclusion Preoperative planning and safe zone delineation are a simple method to assess the relative position of neural and vascular anatomic structures in relation to the surgical area. This method can help spine surgeons to prevent perioperative complications.

Keywords Minimally invasive spinal surgery · Transpsoas lateral approach · Safe working zone · Lumbar fusion · Lumbar discectomy

P. Guérin · A. Bourghli · J. C. Cursolle · J.-M. Vital
Laboratoire d'Anatomie Médico-Chirurgicale Appliquée,
Université Victor Segalen, Bordeaux 2,
146 rue Léo Saignat, 33000 Bordeaux, France

P. Guérin (✉) · I. Obeid · O. Gille · A. Bourghli · S. Luc ·
V. Pointillart · J. C. Cursolle · J.-M. Vital
Unité Rachis 1, Chirurgie orthopédique et Traumatologique,
CHU de Bordeaux, Place Amélie Raba-Léon,
33076 Bordeaux Cedex, France
e-mail: patrick.guerin@chu-bordeaux.fr;
pguerin_patrick@yahoo.fr

Introduction

Spinal fusion is a common treatment for spinal disorders such as disc degeneration, deformity, spondylolisthesis or fracture. Lumbar spinal fusion can be achieved by posterolateral or/and interbody fusion. Interbody fusion can be achieved via the posterior approach (PLIF: posterior lumbar interbody fusion), transforaminal approach (TLIF transforaminal lumbar interbody fusion), anterior approach (ALIF: anterior lumbar interbody fusion). These techniques provide anterior column support and good clinical results but can cause complications [12, 20].

The main disadvantage of the PLIF is the possibility of significant bilateral retraction on the dural sac which can result in incidental durotomies and nerve roots injuries. TLIF still poses risks associated with dysesthetic pain syndromes from nerve roots injuries and incidental durotomies. Vascular complications, ureteral injuries, sexual dysfunction and bowel injury have been reported during ALIF procedures.

The development of minimal access techniques has now been applied to spine fusion. Minimally invasive spine surgery theoretically leads to less blood loss and tissue damage [1] and reduces recovery time. Lateral transpsoas approaches have been used for some years in spinal surgery. In 2004, Bergey et al. [4] described a direct endoscopic lateral transpsoas approach to the lumbar spine as an alternative to the standard endoscopic anterior approach which requires mobilization of the sympathetic plexus and the great vessels.

The minimally invasive lateral retroperitoneal transpsoas approach is a recent technique developed to avoid complications associated with traditional or minimally invasive anterior or posterior approaches to the lumbar spine. This technique was popularized by Pimenta and Ozgur [17]. It was described as DLIF (direct lumbar interbody fusion) and XLIF (extreme lumbar interbody fusion). Its use has been described in the treatment of degenerative disc disease, scoliosis and far-lateral disc herniation [1, 6, 7, 17].

This technique uses a small incision that avoids significant abdominal muscle injury and provides lateral access to the disc space from L1–L2 to L4–L5. The two techniques are based on the psoas muscle splitting technique. The transpsoas approach enables direct access to the lateral spine structures without the need for an access surgeon or bone drilling and an interbody cage can be put in place.

Having crossed the psoas using a drill guide under x-ray guidance, a dilation tube is inserted to create a working space. A spacer is then inserted along the length of the tube which is then withdrawn. The anterior portion of the psoas is retracted at the front, the posterior portion of the psoas and the lumbosacral plexus are reclined backwards. In this way, the intervertebral body is revealed. A discectomy and freshening of the vertebral endplates are then carried out. The size of the cage is then determined and the final cage is inserted. A second posterior incision is made with the XLIF technique in order to palpate the retroperitoneal space before the insertion of instrumentation [17]. The transpsoas approach to the L5S1 disc space is not possible given the location of the iliac crest [6]. XLIF and DLIF approaches do not require retroperitoneal large vessel manipulation for exposure [14].

However, the proximity of the retroperitoneal vessels and ventral nerve roots to the surgical pathway means that there is a risk of injury to these anatomical structures. Accurate knowledge of these anatomic relationships is essential for minimally invasive retroperitoneal transpsoas access and interbody fusion.

It is difficult to accurately choose the point at which to split the psoas muscle. If the entery point is too anterior or posterior, that may increase the risk of vessels or nerve roots injuries respectively. A precise knowledge of the regional anatomy of the lumbar plexus is required for safe passage through the psoas muscle. Preoperative examination of the axial MRI images will allow the surgeon to observe the neural structures at the operative levels and confirm that abdominal vessels do not obstruct the lateral disc space.

Authors have reported data regarding the morphometric measurements and the relationships of these structures [3, 10, 13, 16, 18, 19]. However, most of these studies were performed on cadavers and report on relations of the lumbosacral plexus with the psoas muscle.

The first objective of this study was to analyze the anatomical location of the retroperitoneal vessels and the nerve roots in the retroperitoneal space relative to the intervertebral disc spaces using magnetic resonance imaging (MRI). The second objective was to define safe zones to avoid nerve and vessel injuries when using this minimally invasive approach.

Methods

Patients who underwent MRI examination from July 2008 through September 2010 were selected from our database. Those with a history of spine fracture, previous lumbar surgery, deformity, infection and tumor were excluded from the study.

We retrospectively evaluated lumbar spine MRI in 78 patients (mean age: 50.5 years, ranging from 30 to 71, SD: 10.9), 39 males (mean age: 50.2 years, ranging from 30 to 71, SD: 11.1), 39 females (mean age: 50.7 years, ranging from 30 to 69, SD: 10.8). The total number of lumbar vertebrae measured was 304 levels.

Using this data, one surgeon (PG) carried out measurements of the lower vertebral endplate at each level (sagittal and transversal), disc height (anterior, middle, posterior), position of the nerve roots, position of the right retroperitoneal vessels, position of the left retroperitoneal vessels (Fig. 1a/b). Measurements were performed from

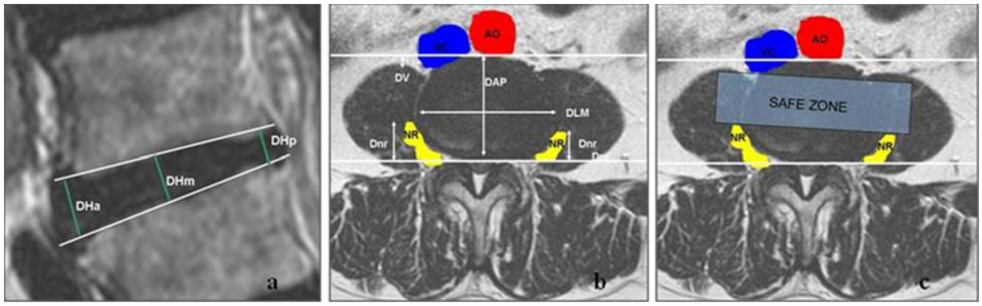

Fig. 1 MRI measurements **a** Measurements of intervertebral disc space height (anterior, middle, and posterior) **b** Measurement of vertebral endplate diameter (*DAP* sagittal diameter, *DLM* transversal diameter), Nerve root position (Dnr) and vascular position (DV) **c** Determination of safe zone

L1–L2, L2–L3, L3–L4 and L4–L5 disc levels and were determined using the PACS software computer digitizer (DxWin Station, Mediasys). Sagittal T2 cuts were used to measure disc space height. Axial T2 cuts were used to measure the other parameters. Only patients with axial images that were parallel to the vertebral endplate were included to ensure the accuracy of the measurements. Extent measurements of the overlap of the retroperitoneal vessels and nerve roots with the lower endplate of vertebral body were performed from both sides of the spine. Measurements were obtained from the posterior or the anterior border of the lower endplate at each intervertebral disc level.

This point is easily detectable on the intraoperative fluoroscopy exam during the surgical procedure. Nerve roots position was measured from their ventral edge to the dorsal edge of the lower endplate of the vertebral body. Then, the extent of the overlap of the retroperitoneal vessels with the ventral edge of the lower vertebral body endplate was measured. The safe zone was defined as the

Table 1 Vertebral and intervertebral disc parameters

	LEVEL	Measured values				95% CI (mm)	
		Mean	Min	Max	SD	Low	High
Vertebral sagittal diameter	L1–L2	39.60	33.70	49.90	2.65	39.00	40.20
	L2–L3	39.26	32.50	48.80	2.77	38.63	39.88
	L3–L4	38.37	33.30	44.60	2.74	37.75	38.98
	L4–L5	39.06	36.20	45.10	2.42	38.52	39.61
Vertebral transversal diameter	L1–L2	48.86	42.00	58.50	3.69	48.03	49.69
	L2–L3	49.01	44.00	56.50	3.39	48.24	49.77
	L3–L4	50.23	44.30	57.60	3.15	49.52	50.94
	L4–L5	52.14	44.50	60.80	4.41	51.15	53.14
Disc height (anterior)	L1–L2	9.01	5.30	16.10	2.02	8.56	9.47
	L2–L3	8.37	5.30	12.30	1.35	8.07	8.68
	L3–L4	10.26	7.00	14.80	1.82	9.85	10.66
	L4–L5	9.23	5.30	16.10	2.74	8.62	9.85
Disc height (middle)	L1–L2	9.65	4.90	15.10	1.75	9.26	10.05
	L2–L3	9.07	6.00	11.40	1.13	8.82	9.32
	L3–L4	10.52	7.00	13.60	1.58	10.17	10.88
	L4–L5	9.60	4.10	15.10	2.38	9.07	10.14
Disc height (posterior)	L1–L2	7.01	4.50	12.00	1.62	6.64	7.37
	L2–L3	6.64	5.00	10.80	1.27	6.36	6.93
	L3–L4	8.34	4.50	12.00	1.75	7.95	8.74
	L4–L5	7.46	4.30	12.00	1.88	7.03	7.88

Measurements of disc parameters are presented in millimeters

The 95% confidence interval was calculated for all parameters

Vertebral AP and LM diameter were measured using axial sections. Anterior, middle and posterior disc heights were measured using sagittal sections relative lower endplate of the vertebral body sagittal diameter that is anterior to the nerve roots and is posterior to the retroperitoneal vessels (Fig. 1c).

Statistical analysis was performed using SPSS software 17.0 (SPSS Inc, Chicago, IL). All data were calculated using 95% confidence interval. Student's t test was used to compare differences between the various levels. p values <0.05 were considered to be statistically significant.

Results

Disc parameters

Data concerning disc parameters (vertebral endplate sagittal diameter and vertebral endplate transversal diameter, anterior disc height, middle disc height and posterior disc height) are presented in Table 1.

Compared to the other levels, interbertebral disc height was significantly higher at L3–L4 level for the three measurements at anterior, middle and posterior parts ($p < 0{,}05$).

Position of the neuro-vascular structures

Data concerning the position of nerve roots, the position of right and left retroperitoneal vessels are presented in Table 2. Extent measurements of the overlap of the retroperitoneal vessels and nerve roots with the lower endplate of vertebral body were performed from both sides of the spine.

The projection of nerve roots is identical on both sides. Overlap of the vertebral body with the nerve roots and retroperitoneal vessels increased progressively from L1–L2 to L4–L5. When analyzing extent of the overlap of the retroperitoneal vessels with the ventral edge of the lower vertebral body endplate, we observed that the right vascular structures were more posterior in comparison to the left vascular structures.

Table 3 Safe working zone

	LEVEL	Mean ratio (% vertebral)	95% CI (%)	
			Low	High
Safe zone	L1–L2	75.3	72.9	77.2
	L2–L3	59.5	57.5	61.5
	L3–L4	51.9	50.4	53.4
	L4–L5	37.8	34.9	40.9

Measurements of nerve roots and retroperitoneal vessels are presented in millimeters and as a percentage of the AP diameter of the vertebral disc. The 95% confidence interval was calculated for all parameters

Safe working zone

Data concerning the safe working zone are presented in Table 3 and Fig. 2a/b.

The safe zone was defined as the relative lower endplate of the vertebral body sagittal diameter that is anterior to the nerve root and is posterior to the retroperitoneal vessels. The safe working zone was 75.3% of the lower endplate of the vertebral body sagittal diameter at L1–L2, 59.5% at L2–L3, 51.9% at L3–L4 and 37.8% at L4–L5 levels. Given the more posterior position of the right vascular structures, the safe zone was systematically

Table 2 Position of nerve roots and retroperitoneal vessels

	LEVEL	Measured values				Mean ratio (% vertebral)	95% CI (mm)		95% CI (%)	
		Mean	Min	Max	SD		Low	High	Low	High
Nerve root	L1–L2	4.37	1.40	9.30	2.12	11.06	3.89	4.84	9.84	12.28
	L2–L3	7.27	4.00	12.70	2.19	18.68	6.77	7.76	17.45	19.90
	L3–L4	8.64	5.40	11.80	1.59	21.91	8.28	9.00	20.88	22.95
	L4–L5	13.97	9.00	20.00	3.01	35.84	13.29	14.65	34.09	37.59
Right vessels	L1–L2	5.30	−12.60	10.90	2.72	13.63	4.68	5.92	12.09	15.16
	L2–L3	8.34	−7.20	12.00	2.72	21.80	7.72	8.96	20.22	23.37
	L3–L4	10.44	4.00	15.40	3.13	26.16	9.73	11.16	24.49	27.82
	L4–L5	10.24	−2.40	16.00	4.20	26.30	9.28	11.20	23.81	28.78
Left vessels	L1–L2	2.48	0.00	6.20	1.69	6.27	2.09	2.86	5.31	7.22
	L2–L3	1.68	−3.50	6.20	2.00	4.37	1.23	2.14	3.21	5.53
	L3–L4	0.74	−6.90	8.00	2.18	2.03	0.25	1.23	0.84	3.23
	L4–L5	4.04	−9.30	11.20	4.05	10.55	3.12	4.95	8.23	12.86

Measurements of nerve roots and retroperitoneal vessels are presented in millimeters and as a percentage of the AP diameter of the vertebral disc. The 95% confidence interval was calculated for all parameters

Measurements were performed using axial sections

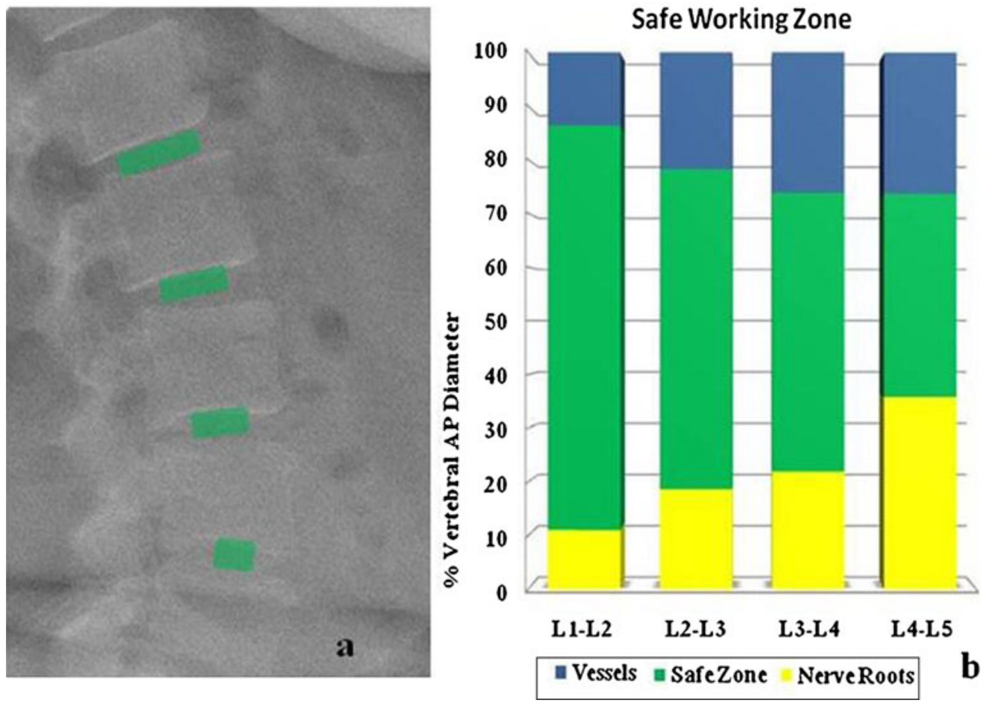

Fig. 2 Safe working zone **a** Schematic representation of safe working zone at L1–L2, L2–L3, L3–L4, L4–L5 levels (in *green*) **b** Overlap of the vertebral body with the nerve root and retroperitoneal vessel

determined on the right-hand side. Right vascular structures may be at high of injury during discectomy and insertion of the interbody cage.

The safe working zone significantly decreases between L1–L2 and L4–L5 ($p < 0.05$).

Compared with L1–L2, L2–L3 levels, the more anterior position of the nerve root and the more posterior position of the retroperitoneal vessels at the L4–L5 level causes a significant reduction of this area.

Compared with the L3–L4 level, we observed that the decrease in size of the safe zone was only secondary to the more anterior position of the nerve roots at the L4–L5 level.

Discussion

Interbody fusion accomplishes the goal of achieving stability of the spine, and maintenance of coronal and sagittal balance. The minimally invasive lateral retroperitoneal transpsoas approach is a recent technique for performing interbody fusion [17]. Compared to ALIF, this approach avoids manipulation of the retroperitoneal vessels and retraction of the intestines [8, 16]. Major vascular complications [5, 9], ureteral injuries, sexual dysfunction and bowel injury have been reported during this anterior approach [2, 8, 11, 15].

When compared with TLIF and PLIF, laterally placed grafts have a much larger area for potential fusion. Further, however XLIF and DLIF permit only anterior fusion.

During this procedure, the main challenge is to assess the correct placement of the implant without direct visualization of retroperitoneal vessels and nerve roots. Ipsi and controlateral large vessels can be damaged during the discectomy, vertebral endplate preparation and implant insertion. Ventral nerve roots and the lumbar plexus can be damaged during the penetration and retraction of psoas muscle.

On MRI study, Hasegawa et al. [13] described the normal anatomic parameters of the lumbosacral nerve roots. They observed that the length of the nerve roots increased progressively to a maximum at L5 and that the nerve root origin was situated at a more cephalad level for the caudal nerve roots.

Regev et al. [18] carried out a morphometric study using MRI exams in order to identify the anatomic position of the nerve roots and large retroperitoneal vessels in relation to the vertebral body. They reviewed exams from normally aligned vertebra, spondylolisthetic segments and segments from the apex of degenerative lumbar scoliosis. They determined that the risk of injury to the ventral nerve roots and retroperitoneal large vessels increased significantly at the L4–L5 level. The major value of this study is its use of easily identifiable radiographic reference points and the relative ratio between the various anatomical structures and the vertebral body for the radiographic measurement. These measures can be used during surgical procedures.

Our observations are consistent with this previous study. We also observed significant narrowing of the safe zone at L4–L5 level. Compared with L1–L2, L2–L3 levels, the more anterior position of the nerve root and the more posterior position of the retroperitoneal vessels at the L4–L5 level causes a significant reduction of this area. Compared with the L3–L4 level, we observed that the decrease in size of the safe zone was secondary to the more anterior position of the nerve roots at the L4–L5 level. This procedure seems to be particularly risky at L4–L5 where there is a theoretical high risk of nerve and vascular damage. These can be devastating complications.

Usually, discectomy and intersomatic fusion by the tranpsoas approach are performed on the left-hand side because of the vascular anatomy. However, it can be performed on the right-hand side, depending on the surgeon's preference and the characteristics of the level being operated on (in the case of asymmetric disc collapse for example). We calculated this safe zone using measurements obtained on the right-hand side since we had observed that the projection of vessels was more posterior on the right than on the left whereas the projection of nerve roots is identical on both sides. We believe that it is important not to overestimate the size of this area by taking only the approach side into account (for the left-hand side). A contralateral disc crack may already exist, or the annulus may be damaged by the forceps during discectomy resulting in a contralateral vascular lesion.

However, a major challenge of MRI studies is the inability to locate the sympathetic trunk, the genitofemoral nerve or other branches of the lumbar plexus that travel through the adipose tissue of the retroperitoneal space (Table 4).

On cadaveric study, Gu et al. [10] determined the location of the lumbar nerve root and sympathetic trunk with reference to the superior border of the transverse process. They found a safe zone between the anterior border of the lumbar nerve and the posterior border of the sympathetic trunk. They observed a narrowing of this area at the L2–L3 level due to the location of the genitofemoral nerve. Moro et al. [16] reported the same observation on anatomic study in relation to an endoscopic retroperitoneal approach. They recommended splitting the psoas more anteriorely than the dorsal quarter of the lumbar vertebral body from the cranial third of the L3 vertebral body and above to prevent nerve injuries. Progressive ventral migration of the plexus on the disc space from L1–L2 to L4–L5 was also reported by Benglis et al. [3] on anatomic study in relation to the minimally invasive transpsoas approach to the lumbar spine.

Postoperative sensory deficit is a well-known complication of the mini invasive lateral transpsoas approach. [6, 14] Intraoperative EMG neural monitoring can also be used to reduce the risk of nerve injury while moving through the psoas muscle with the dilating instrument. [17] It provide additional safety during this procedure, where visualization is limited compared with open procedure.

Table 4 Lumbar plexus

Nerve	Segment	Innervated muscles	Cutaneous branches
Iliohypogastric	T12-L1	Transversus abdominis	Anterior cutaneous ramus
		Abdominal internal oblique	Lateral cutaneous ramus
Ilioinguinal	L1		Anterior scrotal nerves in males
			Anterior labial nerves in females
Genitofemoral	L1, L2	Cremaster (males)	Femoral ramus
			Genital ramus
Lateral femoral cutaneous	L2, L3		Lateral femoral cutaneous
Obturator	L2–L4	Obturator externus	Cutaneous ramus
		Adductor longus	
		Gracilis	
		Pectineus	
		Adductor magnus	
Femoral	L2–L4	Iliopsoas	Anterior cutaneous branches
		Pectineus	Saphenous
		Sartorius	
		Quadriceps femoris	
Muscular branches	T12-L4	Psoas major	
		Quadratus lumborum	
		Iliacus	
		Lumbar intertransverse	

Innervated muscles and cutaneous branches

However, this perioperative exam has been criticized because it only helps identify motor nerves. [6].

Coronal and sagittal view fluoroscopy are usually used to determine the dimensions of the cage and as guidance during the surgical procedure. Dilating and retracting instrumentation must be carefully positioned since if the instrumentation is placed in a posterior position this may result in neural injury especially at the L4–L5 level. [3].

This procedure seems to be particularly risky at L4–L5 where there is a theoretical high risk of nerve and vascular damage. Further, superior edge of the iliac crest limit the potential exposure site to L4–L5. Given our observations, it sems preferable to use alternative techniques such as TLIF or ALIF at L4–L5 level. In our experience, we haded neurovascular complication during transpsoas L4–L5 arthrodesis. We currently no longer use this technique at this level. Our preoperative planning included systematically safe zone determination for the other levels. A simple method consist to report these data on peroperative fluoroscopy views.

Preoperative planning and safe zone delineation are simple methods to assess the relative position of neural and vascular anatomic structures in relation to the surgical area. It permit to evaluate the theoretical risk of neurovascular injury during the procedure. This method can help spine surgeons to prevent perioperative complications and prepare the surgical procedure.

These study demonstrate the importance of preoperative planning in transpsoas approach surgery but cannot remplace anatomical knowledge and special care during surgery. Thorough knowledge of the regional anatomy of the lumbar plexus is required for safe passage through the psoas muscle during the minimally invasive lateral transpsoas approach. Futhermore, intraoperative monitoring and safe zone determination represent a combination of useful adjuncts to minimize neurovascular injuries during transpsoas approach.

Conflict of interest The authors declare that they have no conflict of interest.

References

1. Anand N, Baron EM, Thaiyananthan G, Khalsa K, Goldstein TB (2008) Minimally invasive multilevel percutaneous correction and fusion for adult lumbar degenerative scoliosis: a technique and feasibility study. J Spinal Disord Tech 21:459–467
2. Baker JK, Reardon PR, Reardon MJ, Heggeness MH (1993) Vascular injury in anterior lumbar surgery. Spine 18:2227–2230
3. Benglis DM, Vanni S, Levi AD (2009) An anatomical study of the lumbosacral plexus as related to the minimally invasive transpsoas approach to the lumbar spine. J Neurosurg Spine 10:139–144
4. Bergey DL, Villavicencio AT, Goldstein T, Regan JJ (2004) Endoscopic lateral transpsoas approach to the lumbar spine. Spine 29:1681–1688
5. Brau SA (2002) Mini-open approach to the spine for anterior lumbar interbody fusion: description of the procedure, results, complications. Spine J 2:216–223
6. Dakwar E, Cardona RF, Smith DA, Uribe JS (2010) Early outcomes and safety of the minimally invasive, lateral retroperitoneal transpsoas approach for adult degenerative scoliosis. Neurosurg Focus 28:E8
7. Eck JC, Hodges S, Humphreys SC (2007) Minimally invasive lumbar spinal fusion. J Am Acad Orthop Surg 15:321–329
8. Fantini GA, Pappou IP, Girardi FP, Sandhu HS, Cammisa FP Jr (2007) Major vascular injury during anterior lumbar spinal surgery: incidence, risk factors, and management. Spine 32:2751–2758
9. Garg J, Woo K, Hirsch J, Bruffey JD, Dilley RB (2010) Vascular complications of exposure for anterior lumbar interbody fusion. J Vasc Surg 51:946–950
10. Gu Y, Ebraheim NA, Xu R, Rezcallah AT, Yeasting RA (2001) Anatomic considerations of the posterolateral lumbar disk region. Orthopedics 24:56–58
11. Gumbs AA, Bloom ND, Bitan FD, Hanan SH (2007) Open anterior approaches for lumbar spine procedures. Am J Surg 194:98–102
12. Hackenberg L, Halm H, Bullmann V, Vieth V, Schneider M, Liljenqvist U (2005) Transforaminal lumbar interbody fusion: a safe technique with satisfactory three to five year results. Eur Spine J 14:551–558
13. Hasegawa T, Mikawa Y, Watanabe R, An HS (1996) Morphometric analysis of the lumbosacral nerve roots and dorsal root ganglia by magnetic resonance imaging. Spine 21:1005–1009
14. Knight RQ, Schwaegler P, Hanscom D, Roh J (2009) Direct lateral lumbar interbody fusion for degenerative conditions: early complication profile. J Spinal Disord Tech 22:34–37
15. Kuklo TR, Lehman RA Jr, Lenke LG (2005) Structures at risk following anterior instrumented spinal fusion for thoracic adolescent idiopathic scoliosis. J Spinal Disord Tech 18:S58–S64
16. Moro T, Kikuchi S, Konno S, Yaginuma H (2003) An anatomic study of the lumbar plexus with respect to retroperitoneal endoscopic surgery. Spine 28:423–428
17. Ozgur BM, Aryan HE, Pimenta L, Taylor WR (2006) Extreme Lateral Interbody Fusion (XLIF): a novel surgical technique for anterior lumbar interbody fusion. Spine J 6:435–443
18. Regev GJ, Chen L, Dhawan M, Lee YP, Garfin SR, Kim CW (2009) Morphometric analysis of the ventral nerve roots and retroperitoneal vessels with respect to the minimally invasive lateral approach in normal and deformed spines. Spine 34:1330–1335
19. Uribe JS, Arredondo N, Dakwar E, Vale FL (2010) Defining the safe working zones using the minimally invasive lateral retroperitoneal transpsoas approach: an anatomical study. J Neurosurg Spine 13:260–266
20. Yan DL, Pei FX, Li J, Soo CL (2008) Comparative study of PLIF and TLIF treatment in adult degenerative spondylolisthesis. Eur Spine J 17:1311–1316