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Anterior spinal fusion (ALIF/OLIF/LLIF) with lumbosacral transitional vertebra: A systematic review and proposed treatment algorithm

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1. Introduction

Lumbosacral transitional vertebrae (LSTV) are anatomical variants with adaptations to demands of sacral weight-bearing capacity, with a sacralized L5 better able to handle increased, and conversely, lumbarized S1 handling decreased burdens (Mahato, 2010). Mounting evidence supports a correlation between LSTV and low back pain, sacro-iliac dysfunction, and nerve root symptoms (Quinlan et al., 2006; Lian et al., 2018). The prevalence of LSTV is 30% of the normal population, including those with 6 lumbar vertebrae in 2–5.5% and 3–4 lumbar vertebrae in 1–7% (Bron et al., 2007; McCulloch and Waddell, 1980; Hsieh et al., 2000; Hanson et al., 2010). However, most surgical outcomes research exclude LSTV to optimise patient homogeneity.

Hypermobility of the suprajacent intervertebral space, contributes to increased torque and subsequent intervertebral disc degeneration which is higher than the non-LSTV population (Mallikarjunappa, 2019; Aihara et al., 2005; Farshad-Amacker et al., 2015). Fusion therefore demands enhanced stability measures to achieve a successful union. LSTV includes smaller and more asymmetrical facets and pedicles than non-LSTV anatomy, creating the potential for pedicle screw malposition and sub-optimal anchor strength (Fisher and Bordoni, 2019; Ono et al., 2018). With increasing degrees of sacralisation there is an increased incidence of non-union in these cases (Lee et al., 2018).

Anterior approaches are increasingly popular options for lumbar fusion, including direct or extreme lateral (DLIF/XLIF/LLIF respectively, also known as transpsoas), oblique (OLIF, also known as pre-psoas or ATP; anterior to psoas) and anterior (ALIF, usually considered midline anterior) interbody fusion. Reasons cited for this include a greater intradiscal implant footprint, increased restoration of segmental lordosis, and a lower rate of surgical morbidity, than traditional posterior approaches (Mobbs et al., 2013; Pradhan et al., 2002). Anterior approaches to the spine may be more challenging in the presence of atypical anatomy, which may accompany LSTV. Aside from complexities in identification of the correct level, there are additional anatomical, including vascular, muscular, neural, osseous and technique-based considerations. With a more recent surgical focus on restoration of segmental lordosis, anterior approaches are more commonly performed but without

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Abbreviations

ABF	aortic bifurcation
ALV	ascending lumbar vein
A/O/LLIF	Anterior/Oblique/Lateral lumbar interbody fusion
ATP	Anterior to Psoas (aka OLIF)
AxialLIF	Axial lumbar interbody fusion
CIV	Common Iliac Vein
D/XLIF	Direct/extreme lateral lumbar interbody fusion (aka transpsoas)
GRADE	Grades of Recommendation, Assessment Development, and Evaluation
ICC	ilio-caval confluence
ICT	intercrestal tangent; IS: isthmic spondylolisthesis
IVC	inferior vena cava
LSTV	Lumbosacral transitional vertebrae
MeSH	Medical Subject Headings
MRI	Magnetic Resonance Imaging
PICO	Patient-Intervention-Comparison-Outcome
PLIF	Posterior lumbar interbody fusion
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses

significant literature or collated data on their validity in the LSTV setting.

PICO: In patients with LSTV (P), who undergo an anterior approach for spinal fusion (I), compared to non-LSTV patients (C), the following outcomes were assessed (O).

- What are the relevant anatomical aspects?
- What further technique-based considerations are there?
- What is the incidence of intra-operative surgical deviations and complications ?

2. Methods

2.1. Study design: systematic review

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were followed. A search was conducted using the MEDLINE and EMBASE databases of the English and French literature from January 1, 1970 to July 1, 2022. Inclusion criteria were studies that included lumbosacral transitional vertebrae (LSTV) and details relevant to anterior surgical approaches including lateral (transpsoas, LLIF), oblique (OLIF, ATP) and anterior (ALIF) surgery. The subject headings (MeSH [Medical Subject Headings]) in both databases were used in conjunction with key word variants to build gold-standard search strategies: “lumbosacral transitional vertebrae” “lumbarized” “sacralized” “Bertolotti” “Castelvi” AND any of “vasculature” “iliocaval confluence” “aortic bifurcation” “anterior lumbar interbody fusion” “oblique lumbar interbody fusion” “lateral lumbar interbody fusion”. The reference list of each relevant paper was cross checked for further relevant studies.

Each article from the primary search was evaluated for titles and abstracts for inclusion within the previously described parameters of the study. A secondary review was then taken of the full article where relevant to further discriminate primary findings. Study design, level of evidence and sample size were considered.

A qualitative analysis was performed for the answer to each research question with respect to the available literature across three domains including quantity, quality and consistency of support for the answer. Then, ratings of high, moderate, low, and very low were assigned to the outcome from each question, based on the Grades of Recommendation, Assessment, Development, and Evaluation (GRADE) guidelines (Phillips, 2021). Data was extracted by a single individual and verified independently by a second investigator.

3. Results

A total of 98 articles were identified (Fig. 1), with a final analysis of eight anatomical studies and seven studies on complications and surgical deviations. 83 papers were excluded from the final analysis but were considered for discussion. These excluded studies were relevant to anterior spine surgery (42- excluded LSTV to ensure homogeneity of their population), LSTV (15- LSTV morphometrics in the surgical context, but not anterior approaches), vascular anatomy (19- descriptive), psoas anatomy (1) and an unrelated case report (1), not both LSTV and ALIF/OLIF/LLIF surgery (Fig. 1). Nonetheless, these papers yielded valuable insight in terms of anatomical and approach considerations.

- Sacralized L5 segment transfers motion and torque to the L4/L5 segment. Surgery is invariably required at the L4/L5 segment, also considered the “functional lumbosacral junction”, or “first mobile segment”. Most studies refer to this anatomical variant in association with the partial or complete ossification of the L5/S1 junction (Castellvi classification (Castellvi et al., 1984)).
- Lumbarized S1 segment is otherwise considered as the L5/L6 segment. This is deeper in the pelvis, with a greater sacral slope and pelvic incidence. While of a similar prevalence, this variant is less commonly evaluated in the literature.
- The anterior approach to either case will be very different, which will be discussed.

3.1. Anatomical considerations

Anatomical analysis yielded nine papers, all of which were based on radiological studies, with conflicting findings (Table 1).

Tear-drop psoas is considered where the posterior aspect of psoas major is anterior to the most posterior aspect of the disc or vertebral body, and the most anterior aspect of this muscle is no longer in contact with the vertebrae and detached anteriorly or laterally (Tanida et al., 2017). The psoas muscle was investigated on an MRI series by Louie et al. who differentiated between lumbarized and sacralized cases as part of their analysis, without demonstrating a higher incidence of tear-drop psoas in LSTV (contrasts with findings from complication/surgical deviation studies below) (Louie et al., 2017). It was noted on axial imaging at L4-5, that the psoas migrated anteriorly and laterally, with anterior migration of the lumbar plexus and posterolateral migration of the iliac vasculature. This may increase the risk of neurovascular injury during LLIF and OLIF procedures.

Gündüz and Josiah et al. found the LSJ to lie deeper in the pelvis in LSTV, where the intercrestal tangent (ICT) is more likely to cross at L4, a finding often consistent with a greater pelvic incidence and with a more horizontal sacrum (Gündüz et al., 2019; Josiah et al., 2017). Psoas muscles appeared to rise ventrally and laterally in patients with LSTV (Becker et al., 2022). These series were much smaller than that of Louie et al. The ascending lumbar vein (ALV) was found to course over the disc space into venous union and with the higher merger of the iliac veins. Access through the bifurcation of the inferior vena cava effectively reduced the annulotomy window and the size of the graft that can be used (Lee et al., 2018). It was noted in LSTV cases, that where the psoas was not to the side of the vertebrae, the iliac vessels occupied this space instead.

Molinares et al. analysed retroperitoneal trajectories to the lumbar spine on MRI, finding that although transitional anatomy has a greater incidence of altered vascular anatomy, it does not appear to negatively impact the oblique corridor to L2-S1 discs (Molinares et al., 2016). It was also found, while not restricted to LSTV, that with a lower ICC, direct anterior access to L5S1 was less probable. In 3 of 8 cases of ICC at mid-L5,

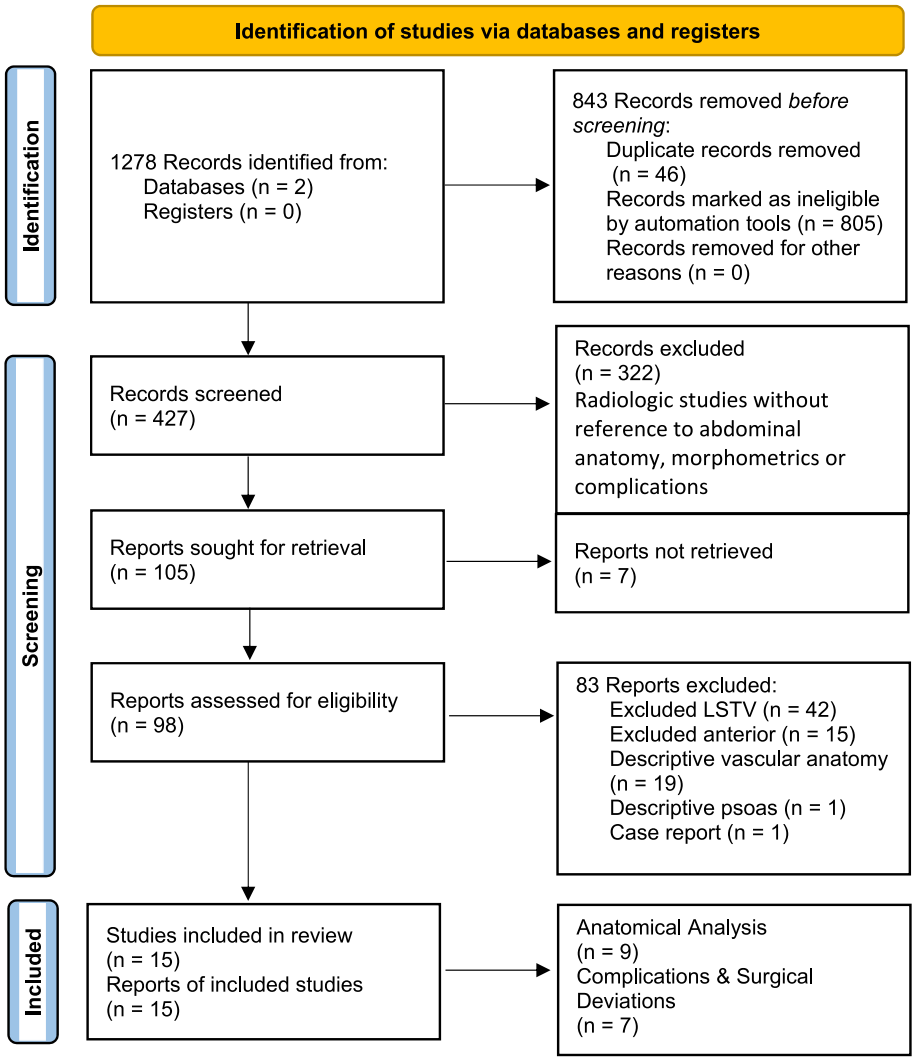

Fig. 1. Flow diagram of systematic review. PRISMA (Page et al., 2021).

oblique access was found instead. Chithriki, Lee, Jagannathan and Turelli et al. (Chithriki et al., 2002; Lee et al., 2007; Jagannathan et al., 2017; Tureli et al., 2014) found similar relationships between vasculature and functional lumbosacral junction, where either or both the ABF and ICC were positioned more cephalad with sacralized L5 cases and more caudal in lumbarized S1 cases. While Becker et al. enumerated as 4L 4L-LSTV, 6L and 6L-LSTV, results were similar to the above- ICT, ICC & ABF were more cephalad in sacralisation and lower in lumbarisation cases (Becker et al., 2022).

3.2. Technical consideration and complications

Intra-operative surgical deviations and complications analysis revealed seven studies (Table 2).

Weiner et al. noted in 11/12 sacralized L5 cases, that the surgical approach to the "functional lumbosacral junction" (L4L5 level) required access lateral to ABF/ICC [28, Fig. 2A 2B]. The ascending lumbar vein was more proximally located (closer to the junction with the IVC) and could form a common trunk with the iliolumbar vein. Both the median sacral and the ascending lumbar were found to be of increased diameter. Smith and Voyadzis et al. found difficulties with a lateral transpsoas approach, which had a high conversion to PLIF or AxialIF. Similar to Josiah et al., there was a higher prevalence of tear-drop psoas (Lian et al., 2018; Voyadzis et al., 2014), which prevented safe access to the disc space. Neurological injury to the femoral plexus was a risk factor in these cases, but there was no increased potential for vascular injury (Smith et al., 2012a). Fantini et al. reviewed a retrospective clinical series of all ALIF, with a 2.9% (10/345) rate of vascular injury, including one LSTV who suffered a left CIV injury with inadequate mobilisation of the iliac vessels, using a left paramedian approach (Fantini et al., 2007). The authors noted cephalization of the last mobile segment and/or caudalization of the iliac vein confluence, such that the last mobile segment is often located directly dorsal to the ICC, mandating an approach lateral to the ABF & ICC for the last mobile segment necessitating ligation and division of the ascending iliolumbar vein to obtain exposure.

Moreau et al. noted in a series of 20 anterior fusions in L4-L5 isthmic spondylolisthesis (IS) where LSTV (sacralized L5) was present in 12 (60%) (Moreau et al., 2016). In LSTV cases, L4-L5 was below the projection of the iliac crest in 92%. The CCI was more cephalad and there was a trend towards a steeper confluence angle of the common iliac veins in this group. No complication was noted, even if the approach was unusually difficult in 11 cases. The left CIV was noted to course transversely across the left anterolateral aspect of the L4-L5 disc and L5 vertebral body, increasing the risk of vascular injury. Contrary to other studies, the recommended approach for L4-L5 IS was a pure anterior approach (midline) or an exclusive posterior approach. Nourian et al. demonstrated increased blood loss in LSTV ((347 mls vs. 262 mls non-LSTV) (Nourian et al., 2016). Chung et al. demonstrated OLIF at L56 was technically feasible without reporting specific complications (Chung et al., 2018).

Table 1
Studies included in Anatomical Analysis n = 9. ICT: Iliac crest tangent, RR: retrospective review, PR: prospective review.

Author	n (LSTV/ Total)	Study Design	Level of Evidence	Findings	GRADE
Louie	28/ 263	MRI study	3	No association between teardrop psoas anatomy and LSTV	Mod
Gündüz	39/55	Control study, radiographic	3	ICT crossed the spine more often at L4 In LSTV than controls, ABF lower in LSTV 75.8% vs. 98.2%*	Mod
Josiah	28	CT & MRI	4	LSTV-iliac crest is more likely to be above the L4–5 disc space, association between LSTV and teardrop psoas anatomy, more cephalad ICC and AB	V Low
Molinares	6/100	RR MRI	4	LSTV does not negatively impact the oblique corridor to the L2–S1	V Low
Chithriki	37/ 442	Pr MRI	3	Sacralisation L5- ABF more cephalad, more caudally in lumbarisation. ICC not measured (ABF at L3 in 59% in LSTV v L4 in 67% non-LSTV)	Mod
Lee	127/ 534	MRI	4	More cephalad ABF and ICC in sacralisation cases	Low
Jagannathan	58/ 312	MRI	4	More cephalad ABF and ICC in sacralisation cases	Low
Tureli	505	MRI	4	More cephalad ABF in sacralisation cases and more caudally in lumbarisation. ICC not measured	Low
Becker	53/ 819	CT	4	ICT, ICC & ABF was lower in 6L, higher in 4L, Psoas more anterior in LSTV	Mod

Table 2
Studies included in Intra-operative Surgical Deviations and Complications Analysis n = 7. RR: retrospective review, CS: Case series, IS: isthmic spondylolisthesis.

Author	n (LSTV/ Total)	Study Design	Level of Evidence	Findings	GRADE
Weiner	11/12	RR	3	ALIF: Complications not reported. Approach lateral to ICC, similar to L4L5 approach.	Mod
Smith	10/351	RR	4	LLIF: L56 challenging, 8/10 displayed neuromonitoring findings preventing successful LLIF, teardrop-shaped psoas found.	Mod
Voyadzis	3	CS	4	1/3 cases of abandoned LLIF had LSTV which was L5L6 instead of L4L5.	V low
Fantini	1/345	RR	4	ALIF: analysis of major vascular injury, total 10 of which 1 was LSTV	Mod
Moreau	12/20	RR	4	ALIF for L45 IS, No complications, L4-L5 was below the projection of the iliac crest in 92% of cases, left common iliac vein courses transversely across the left anterolateral aspect of the L4-L5 disc and L5 vertebral body favour a pure anterior approach (midline) or an exclusive posterior approach	Mod
Nourian	49/204	RR	4	Higher blood loss (347 v 262) compared to without LSTV	V Low
Chung	8/127	RR	4	OLIF, No intra-operative outcomes. Among the 127 cages inserted, 8 (6.2%) at L5-6 (lumbarisation) level. No intra-operative outcomes.	V Low

4. Discussion

In the treatment of lumbar spine pathologies, employing anterior approaches for spinal fusion, including ALIF, OLIF and LLIF are increasingly prevalent lending to minimally invasive concepts, deformity corrections and high fusion rates. As the trajectory varies from direct anterior, to flank, to lateral, the obstacles in anterior approaches include the level and nature of the vasculature, the position of the psoas muscle and the iliac crest respectively (Fig. 7). Most common complications reported in over 11000 all-level ALIFs were venous injury (3.2%), retrograde ejaculation (2.7%), neurologic injury (2%), prosthesis related (2%), postoperative ileus (1.4%), superficial infection (1%) and others (1.3%) (Bateman et al., 2015). Arguably lower than this are early clinical results and complications associated with OLIF, which have shown incisional pain (2.2%), sympathetic chain injury (1.7%), neurological deficit (1.1%) and iliac vessel injury (1.1%) (Silvestre et al., 2012). Taking an accommodative approach in each case is critical to achieving surgical objectives, particularly where LSTV anatomy is expected to deviate from normal patterns (Fig. 2A & B). At the outset, osseus morphology with LSTV will demonstrate abnormal L5-Iliac crest enlarged and dysplastic transverse processes or enumeration variance in the case of lumbarisation. In this context, the evaluation of anatomic studies must be interpreted in terms of access to above the standard lumbosacral junction at the suprajacent L4/5, or below, at the L5/6 levels.

Vascular awareness while accessing L4/5 will be in the presence of a more cephalad ABF and ICC with sacralized L5 (far greater prevalence of pathology), but with safer experiences of approaching L45 lateral to the ABF/ICC. Conversely access to the deeper L5/6 level will be in the

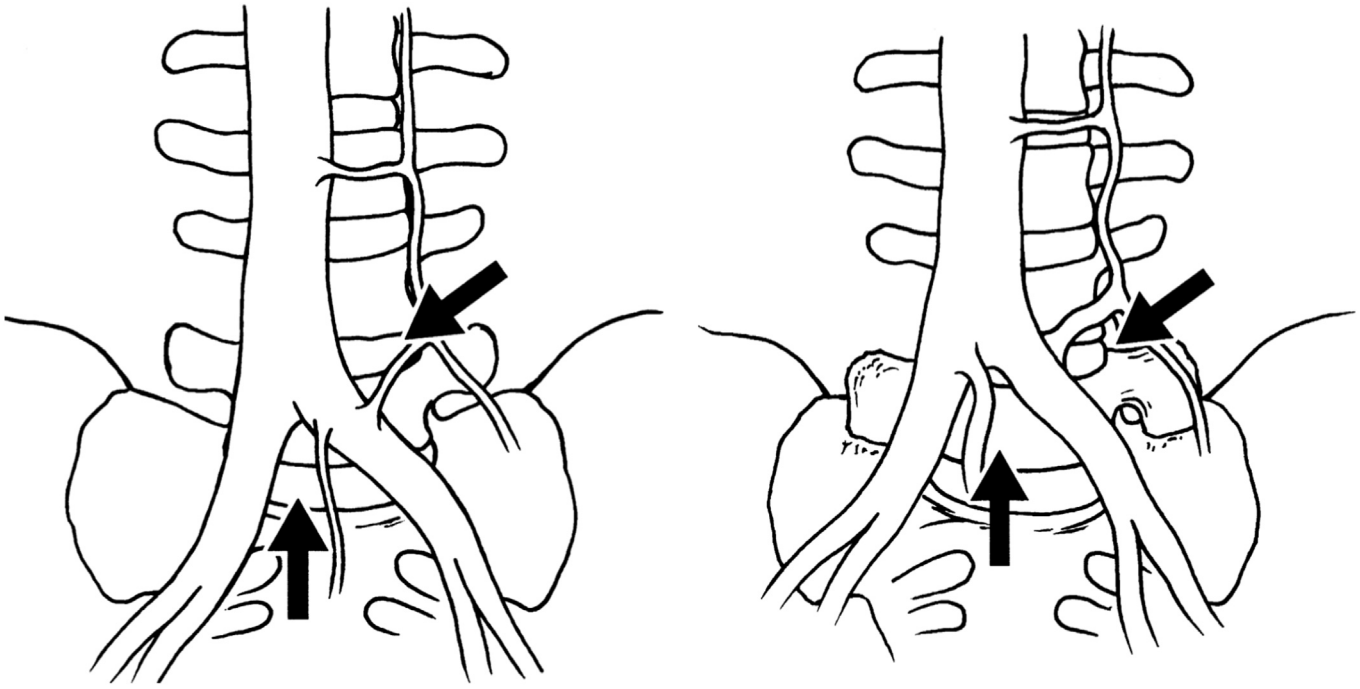

Fig. 2. A&2B: Adapted from Weiner et al. (Weiner et al., 2001). Access options on midline and lateral approaches for "Normal" and LSTV vascular anatomy. A: "Normal": midline approach between ABF and ICC, lateral approach to L45. B: LSTV: midline approach is less likely whereas lateral approach may be considered, accepting anatomical variants including ABF, ICC and ALV.

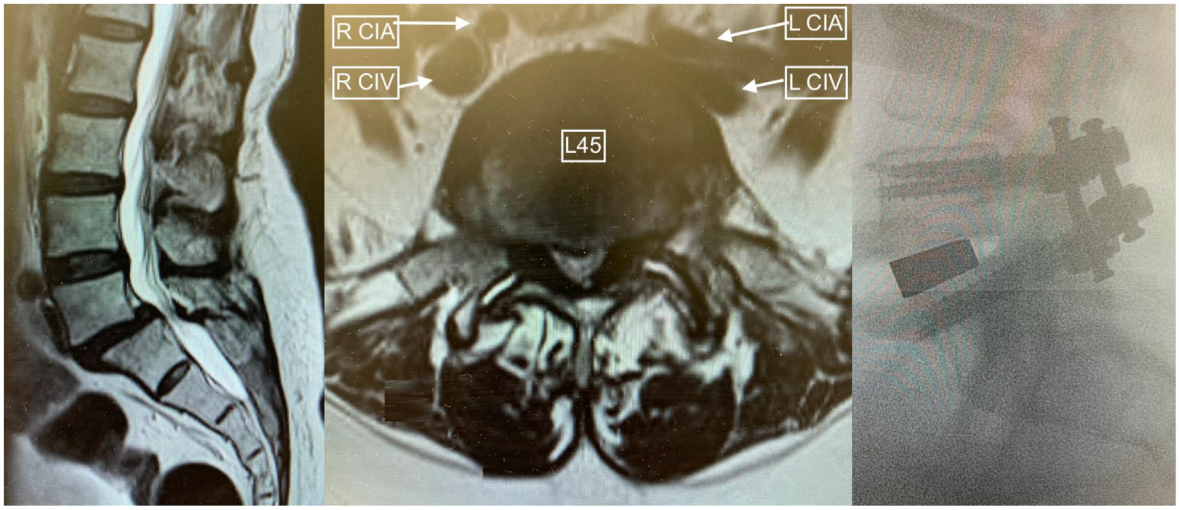

Fig. 3. Sacralized L5 case. a: disc degeneration at the functional (L45) lumbosacral level; b: axial MRI view of pathology, fluid in facets indicating significant segmental mobility, anterior vessels demonstrate right side artery and vein (R CIA and CIV) which are not in the surgical corridor, left side (L CIA and CIV) are in close proximity, traversing the surgical corridor from medial to lateral. Optimal disc access was unclear. Left side OLIF approach anterolateral to the disc revealed inadequate access but safely allowed access medial to the left CIA and CIV, thus caudal to the ABF/ICC; c: intervertebral cage and pedicle screws in situ.

presence of a more caudal ABF and ICC in lumbarized S1 (Fig. 6). In non-LSTV, the laterality of vessels has greater implications with OLIF to L5S1, as the right side is considered to be more accessible (Song et al., 2019). The superior hypogastric (sympathetic) plexus should be considered because it courses on the left side of the aorta, anterior to the LCIV. The left-side approach to the L5S1 disc could damage the superior hypogastric plexus, resulting in excess vasodilation and warmth in the left foot and/or retrograde ejaculation (Paraskevas et al., 2008). Evaluation of vascular position and access corridor when evaluated on supine MRI scanning must recognise the change in position of these structures when operating from an oblique or lateral approach.

LLIF should be considered a relative contra-indication in LSTV, largely due to tear-drop psoas, interposed iliac vessels in the lateral vertebral-psoas gutter and a higher intercrestal tangent (ICT). Evaluation of the position and size of the psoas should also be considered with an oblique approach (OLIF), for example, for L4L5 fusion with sacralized L5. While reported for LSTV, Louie et al. did not find a higher incidence of tear-drop psoas in LSTV, accepting that this analysis was done on a non-surgical cohort. Lumbarized S1 is a relative contraindication for lateral transpsoas interbody fusion (L5/L6), largely because of a psoas that resembles that of the normal L5/S1 level (Smith et al., 2012b). A sacralized L5 may contain variant psoas anatomy and an anteriorly displaced

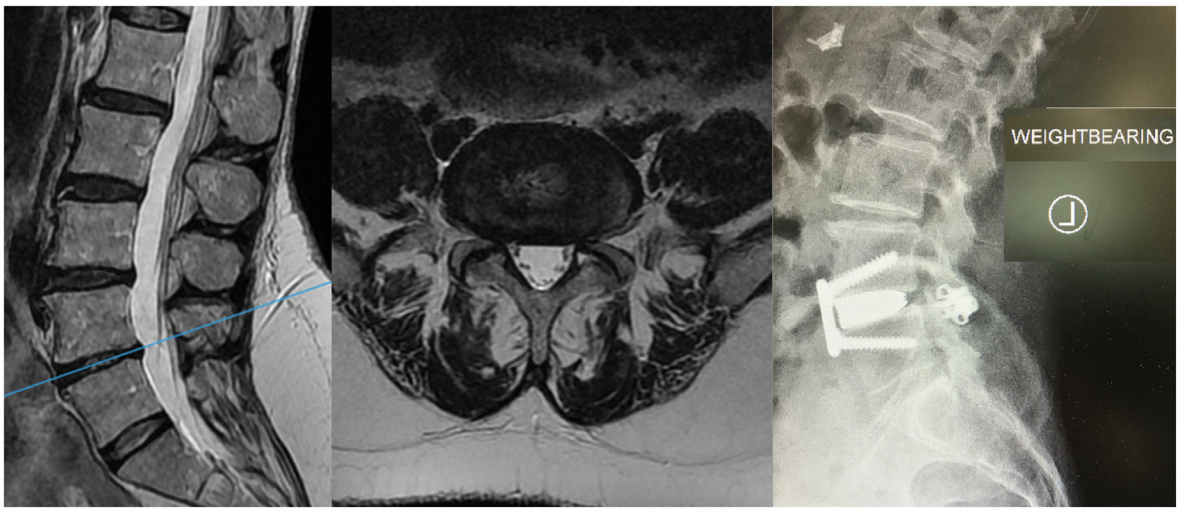

Fig. 4. Sacralized L5 case. a: 10 years of mid-flexion instability, mild MRI evidence of disc degeneration at the functional lumbosacral level; b: high bifurcation revealed direct anterior access to the disc space, normally considered approachable from anterolateral access; c: intervertebral cage with facet joint wedges, note the high inter-crestal tangent (mid-L4).

Fig. 5. Sacralized L5 with coronal deformity. a: MRI T2 b: MRI Axial L4L5 (functional lumbosacral joint). The surgical approach to the bifurcation appeared accessible through a midline approach caudal to the bifurcation. The L45 transitional segment disc height approximates that of a L5S1 disc; c: an OLIF approach (semi-lateral position, flank incision) was taken as a utilitarian approach. The disc was difficult to access through the midline and a lateral trajectory was taken instead. This required a second IO window but ultimately was safely achievable with OLIF. d: final radiograph with partial coronal correction.

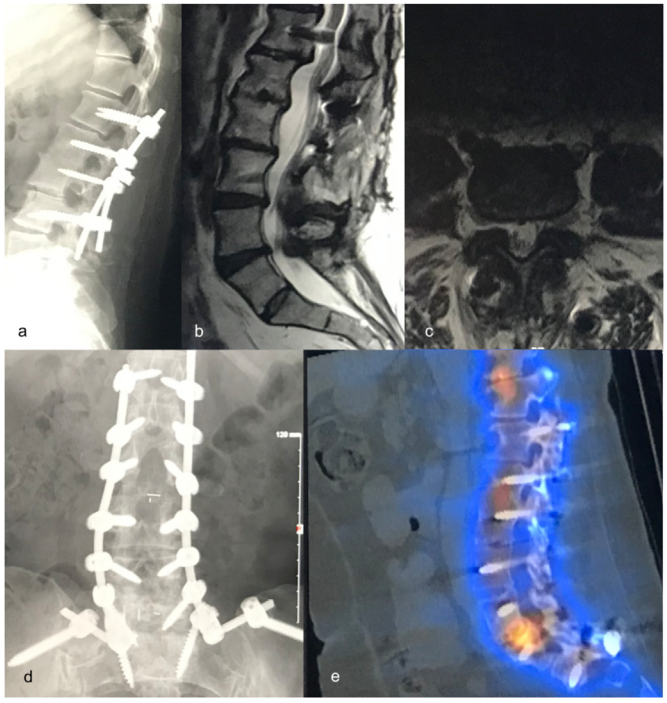

Fig. 6. Lumbarisation L56, a: pre-existing L1-L4 spinal instrumentation, non-contiguous stenosis and instability L56 requiring revision with extension to the pelvis, b: MRI T2, distal segment degeneration L4L5 L5L6, c: MRI T2, L56 facet erosion, achievable midline vascular access noted (not used), d: post-revision radiograph, instrumentation L1-Pelvis with L56 bullet cage, e: SPECT scan, pseudarthrosis L56 with cage subsidence and cyst formation. An anterior approach at L56 would have allowed a greater implant footprint and height, thus optimising segmental lordosis and fusion.

lumbar plexus (Xu et al., 2018). As the psoas travels caudally, the plexus generally migrates from a dorsal to ventral location on the lateral aspect of the disc. Given the recent trend for prone lateral interbody (LLIF) or single position 360° surgery (LLIF with percutaneous pedicle screw insertion), LSTV cases should not be considered for these procedures for the reasons outlined.

An L4/5 IS yielded a 60% incidence of LSTV, with smaller pars interarticularis, pre-disposing the patient to IS but also alternative vascular findings (Moreau et al., 2016). Contrary to the findings above, the authors found it better to access the L45 disc through a direct anterior

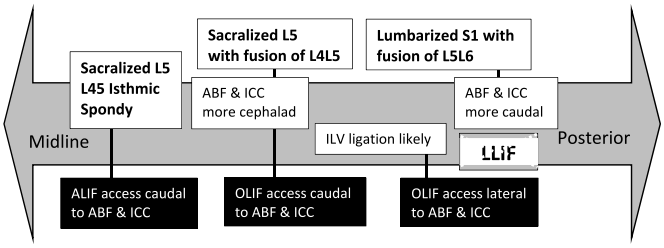

Fig. 7. Algorithm for LSTV abdominal approach. ABF: Aortic Bifurcation; ICC: Ilio-Caval Confluence. Dashed line indicates contra-indication.

route (ALIF), because of significantly more cephalad ABF/ICC. Ould-Slimane et al. (2020) previously noted that IS at L5S1 induces a geometric deformation of the lumbosacral hinge which modifies its anatomical relations with the ICC. The anterior approach to L45 in the presence of an L5S1 IS is possible between the iliac veins (Xu et al., 2018).

One must display a heightened awareness of appropriate level surgery with transitional anatomy. Sacralized L5 exhibits a spectrum of elongated transverse process(es) to complete sacral fusion (Castellvi et al., 1984). Intra-operative display of pre-operative radiographs may also help recognition of the morphology of the fusion level. The lumbosacral junction lies deeper in the pelvis than non-LSTV, where the ICT is more likely to cross at L4 (Louie et al., 2017).

Major haemorrhage is a known and feared complication of anterior access surgery. While instances were reported, this review did not find significantly higher incidences of major haemorrhage in LSTV cases. Intra-operative blood loss was reported as higher than non-LSTV cases (Fantini et al., 2007). While vascular complications were not significantly higher, surgical deviations were more common. However, lessons learned from difficult access cases can mitigate against this, particularly with recognised psoas, vascular and osseus factors on pre-operative evaluation (Fig. 2). Vascular injuries are under-reported and can be unforgiving. While standardising the anterior approach normally provides a "safe system" routine, varying the side or the angle of the approach must raise the awareness of the operator that the safe zone for dissection may therefore be the inverse of the normal routine. Marking the retractors to remind the operator would help mitigate against surgical injury. This is also relevant for pledget dissection which is best conducted in the direction of the relevant vessel as opposed to away from it.

While anatomic studies have identified a lower ABF and ICC in lumbarisation cases (L5/L6), surgical studies have not shown details of surgical deviations or complications. Series of fusions at L5/L6 (any approach) are not described in the literature. Described alternative fusion methods for L5/L6 include PLIF, AxialLIF (Weiner et al., 2001) or OLIF (Nourian et al., 2016) but complications have not been reported. L56 patients have up to 20° higher pelvic incidence and up to 11° greater sacral slope than standard measurements respectively (Price et al., 2016). The pubic bone may therefore inhibit access to L56 if using ALIF.

These techniques must also incorporate other known approach considerations. Correct positioning warrants supervision and communication, with co-ordination of intra-operative imaging. A perivascular fat-strip can determine retraction potential of the iliac veins, although it is less likely to exist at LS levels and its presence is not proven as a safety factor. Requirement for secondary insertion of pedicle screws or osteotomy is influenced by the pathology, including degenerative deformity, isthmic spondylolisthesis, high sacral slope and segmental hypermobility/instability or ability to safely apply a plate (Ahern et al., 2020). Exposure to the disc space will dictate annulotomy size, affecting intradiscal height correction. Additional factors influence the optimal approach including previous abdominal scarring or truncal obesity. Fusion of multiple levels may necessitate mobilisation of the iliac vein or IVC which has a higher vascular injury rate. Placing the patient in a semi-lateral position and using OLIF therefore allows versatility where it allows safe access to either medial or caudal to ABF/ICC (Molloy et al., 2016). Key to this utilitarian approach is using the appropriate obliquus internus approach window that facilitates optimal access to the disc space. This obviates the need for converting a failed OLIF procedure into a PLIF/TLIF/AxiaLIF. Recognising safe boundaries is of critical importance and therefore, aborting surgery to instead provide posterior fusion is safer than a significant vascular injury with its associated blood loss and risk of mortality.

4.1. Illustrative cases are described (Figs. 2-5)

While a criticism of posterior approaches for LSTV is the increased risk of non-union, a limitation of this review was that rate of fusion was not reported in the analysed studies. Arterial thrombosis is another recognised complication of this approach, not reported in the literature on LSTV, and relevant where anterior or lateral osteophytes would dictate the approach to the disc space instead. Disc height restoration is a commonly quoted feat of ALIF, OLF and LLIF but these were not reported for LSTV. The studies were heterogenous, with findings from radiological, cadaveric and surgical research. However, surgical outcomes are contingent on these pre- and intra-operative factors.

In conclusion, this systematic review seeks to identify characteristics of anterior approaches to the LSTV spine and promote identification of safe surgery for LSTV using the anatomical and surgical papers reporting on the subject. While anatomy is usually altered in these cases, vascular, muscular and osseous anatomy is predictably altered, sufficient on pre-operative analysis to facilitate a surgical plan. Fluid versatility is required on behalf of the spine surgeon to optimise the approach and in particular, interchange between ALIF and OLIF, access the appropriate level lateral or caudal to the ABF/ICC and mitigate for potential posterior surgery if needed. The OLIF approach seems a more utilitarian option in this regard. This review also arms the surgeon with enhanced awareness and insight for anterior approaches in the non-LSTV population, providing a further layer of safety and optimisation of results.

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Author statement

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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