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Asymmetric sacroiliac joint anatomy in partial lumbosacral transitional variations: Potential impact on clinical testing in sacral dysfunctions

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ABSTRACT

Lumbosacral transitional vertebrae (LSTV) anomalies may present as bio-mechanical dysfunctions leading to low back pain (LBP). Unilateral or incomplete/partial LSTVs have been documented to be associated with significant sacroiliac joint (SIJ) joint asymmetries. Objective evaluation of outcomes from routine clinical testing for sacral dysfunctions on these subsets of LSTV cannot be found in the literature. Based on quantitative studies available on LSTV-associated anatomical variations at the SIJ, this study hypothesizes probable outcomes of standard palpatory clinical tests used to evaluate sacral dysfunctions in unilateral LSTV anomalies. Since LSTV is reported in a sizeable percentage in the general population and due to its proposed etiological relationship with LBP, these entities warrant attention in terms of the anatomical bases of related clinical assessments and their outcomes, as proposed in this hypothesis.

Introduction

Lumbosacral transitional variations (LSTV) are commonly detected in clinical practice (Fig. 1) [1–3]. The prevalence of LSTV in the population is estimated to be around 12.5% (range = 4.0%-35.9%), with alterations in lumbar spine curvature, disc degeneration, peripheral nerve entrapment, LBP and SIJ dysfunctions being reported with these anatomical variations at the lumbosacral junction [4,5]. A subset of these variations such as unilateral L5-S1 accessory articulations (Castellvi Type II A), partial/incomplete/unilateral sacralisation (partial fusion of L5 vertebra/Castellvi Type III A), partial/incomplete/unilateral lumbarization (separation of S1segment), or mixed Type IV anomalies have been characterized by Castellvi and other investigators as asymmetric anomalies [6–9]. Such unilateral LSTVs at the lumbosacral junctions are also associated with ipsilateral asymmetries of auricular surface dimension at the sacroiliac joint and facet morphology. Partial LSTVs usually show up as significantly larger dimensions of the auricular surface area and height on the side of the lumbosacral fusion when compared to the unfused side [6,10,11]. Accordingly, significant variability in the sacral articular dimensions may affect load bearing equilibrium and dynamics at the sacroiliac joints [11–14]. As such, these variations in weight bearing may result in back pain, unilateral sacral dysfunctions that can be diagnosed with clinical dysfunction testing [1,15–17]. Signs and outcomes of palpatory clinical evaluations have been well documented in lumbosacral and sacral dysfunctions [18–20]. However, outcomes of clinical dysfunction testing (for sacral torsions) in LSTV anomalies have neither been hypothesized or documented, especially in partial LSTVs that in most instances, present with (i) morphological asymmetries of the osseous sacroiliac articulations, (ii) facet tropism, and/or (iii) variations in joint ligamentous attachments [3,13,21–23]. Although there are different anatomical variants observed across the LSTV spectrum, the objective of this hypothesis is to discuss variants that are partial/unilateral and result in asymmetric morphological changes at the sacroiliac articular areas. Accordingly, this study hypothesizes how these specific morphometric changes may impact clinical testing in LSTV-associated lumbosacral and sacroiliac (sacral) dysfunctions. The hypothesis presented in this study attempts to elucidate the possible relationship between unilateral LSTVs and sacral dysfunctions and attempts to predict outcomes of common clinical tests that are applied to diagnose such dysfunctions. For the purpose of facilitating the understanding of the hypothetical concept, hypothesis for partial/incomplete sacralization and lumbarization, and the hypothesis for unilateral accessory L5-S1 articulations have been presented separately.

The PubMed database was searched for publications specifically reporting quantitative, morphometric studies on sacral dimensions that compared sacroiliac joint surfaces in the normal and LSTV associated lumbosacral junctions. Reports on the mechanisms of clinical testing in sacral dysfunctions, sacroiliac asymmetries, associated biomechanical alterations and concomitant joint dysfunctions were reviewed from the

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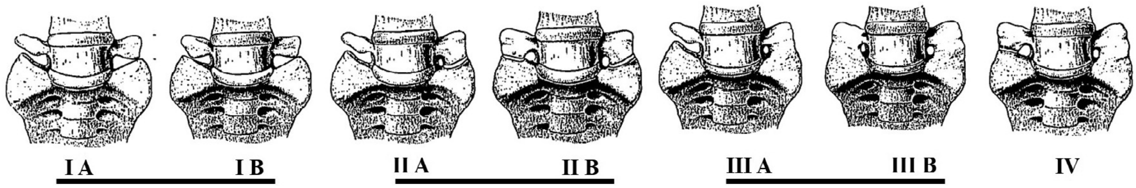

Fig. 1. Castellvi et al. four subtype LSTV classification. Type I includes unilateral (IA) or bilateral (IB) dysplastic transverse processes (19 mm wide, ≥ cranio-caudal). Type II incomplete unilateral (II A) or bilateral (II B) 'accessory' diarthrodial articulation between an enlarged transverse process of the preceding lumbar vertebra and the sacral ala. Type III LSTV, unilateral (III A) or bilateral (III B) . Type IV was described as a mixed feature of Type II transition on one side and a Type III on the other . This classification does not classify sacralization (6-segment sacrum) or lumbarisation (5-segment sacrum) as two dustinct morphological entities.

Table 1

The table shows a representative transitional state, the left-sided incomplete Sacralisation/Lumbarization. A left-sided incomplete fusion with smaller left auricular surface (column one) with common types of dysfunctions (column two), the predicted outcomes of routine clinical tests (column three to eight). L = Left; R = Right; LSTV = Lumbosacral Transitional Vertebrae; ILA = Infro-lateral Angle; LUF = Left Unilateral Flexion; LUF = Left Unilateral Flexion; LUE = Left Unilateral Extension; SS = Sacral Sulcus; ↑ = in greater degrees than assessed in normal sacrum for the same dysfunction; = ↓in lesser degrees than assessed in normal sacrum for the same dysfunction due to osseo-ligamentous asymmetry in unilateral LSTV.

Transitional Anomaly	Problem	Dysfunctional LSTV	Seated Flexion Test	Deep Base/ Sacral Sulcus	ILA	Spring Test	Comments
Incomplete Sacralisation/Lumbarization (e.g. Left sided asymmetry with smaller auricular surface on the left/unaffected side)	Unilateral (left) Flexion or Extension	LUF	L	L	L	− ve	More common than RUF
		LUE	L	R	R	+ ve (Left)	More common than RUE
	Bilateral Flexion or Extension	Bilateral F	L > R	L	L	− ve	–
		Bilateral E	L > R	–	–	+ ve (> on the Left)	SS, ILA comparatively shallow on the left
	Torsion In Flexion (forward)	L on L	↑R	↓R	↑L	− ve	Less common than R on R
		R on R	↓L	↑L	↓R	− ve	More common form
	Torsion In Extension (backward)	L on R	↑L	↓R shallow	↑L	+ ve	More common form
		R on L	↓R	↑L shallow	R↓	+ ve	Less common than R on L

Table 2

The table shows a representative transitional state, a left-sided unilateral L5-S1 accessory articulation (first column) with slight left side-bend (left sacral axis), with common types of dysfunctions (column two), the predicted outcomes of routine clinical tests in these anomalies (column three to eight). L = Left; R = Right; LSTV = Lumbosacral Transitional Vertebrae; ILA = Infro-lateral Angle; LUF = Left Unilateral Flexion; LUF = Left Unilateral Flexion; LUE = Left Unilateral Extension; SS = Sacral Sulcus; ↑ = in greater degrees than expected in normal sacrum for the same dysfunction; = ↓in lesser degrees than expected in normal sacrum for the same dysfunction due to osseo-ligamentous asymmetry in unilateral LSTV. The study hypothesizes L5 rotation to be minimum in these LSTVs, thereby the predominant axis for torsions becoming the L5 side-bend. The corresponding outcomes are italicized.

Transitional Anomaly	Problem	Dysfunction Diagnosis in LSTV		Seated Flexion Test	Deep Base/ Sacral Sulcus	ILA	Spring Test	Comments
Left-sided L5- S1 Accessory Articulation (e.g. Left sided asymmetry with larger ligaments on the left/affected side)	Unilateral Flexion or Extension	RUF		R	R	R	− ve	More common than LUF
		RUE		R	L	R	+ ve (Right)	More common than LUE
	Bilateral Flexion or Extension	Bilateral F		R > L	R	R	− ve	–
		Bilateral E		R > L	–	–	+ ve (> on the Right)	SS, ILA comparatively shallow on the right
	Torsion In Flexion (forward) Left side-bend	Left Rotation	L on L	↑R	↑R	L	− ve	L on L more common
			R on R	*L*	*L*	*↑R*	*− ve*	
		Right Rotation	L on L	↑R	R	L	− ve	L on L more common
			R on R	*L*	*L*	*↑R*	*− ve*	
	Torsion In Extension (backward) Left side-bend	Left Rotation	*L on R*	*R*	*↑R*	*L*	+ ve	R on L more common
			R on L	↑R	L shallow	R↑	+ ve (Right)	
		Right Rotation	*L on R*	*R*	*↑R*	*L*	+ ve	R on L more common
			R on L	↑R	L shallow	R↑	+ ve (Right)	

literature. The outcomes of these clinical tests were reviewed in the light of the anatomical asymmetries at the SIJ and a set of hypotheses was formulated that could explain mechanistic relationships between unilateral LSTV anomalies and potential outcomes of sacral dysfunctions being tested. The hypotheses related to the clinical testing are discussed below. The hypothetical outcomes of the tests have been compared with normal non-LSTV lumbosacral junctions and sacroiliac joints[Tables 1 and 2] and figures (Figs. 2 and 3). Considering the limitations of this hypothesis-only study, investigative palpatory testing data from normal or LSTV-related spines per se, have not been included in this project.

Hypothesis and discussion

A. Unilateral sacralisation/lumbarization (*Castellvi Type IIIA*): In unilateral sacralisation/lumbarization, the dimension of the osseous SIJ has been found to be smaller on the unfused side [11]. Additionally, studies have shown the sacroiliac, ilio-lumbar and lumbosacral ligaments on the unaffected, non-LSTV side to be smaller compared to the LSTV-affected side in the same individual, or when compared to the dimensions in the general population. These morphological alterations may have a cause-effect relationship related to the hypermobility observed on the contralateral, non-LSTV affected joint. This may eventually present as dysfunction and pain on the non-LSTV side [24,25]. Some studies have reported the pain to originate from the non-LSTV side at the initiation of LBP. Possibly, the unaffected side could be more

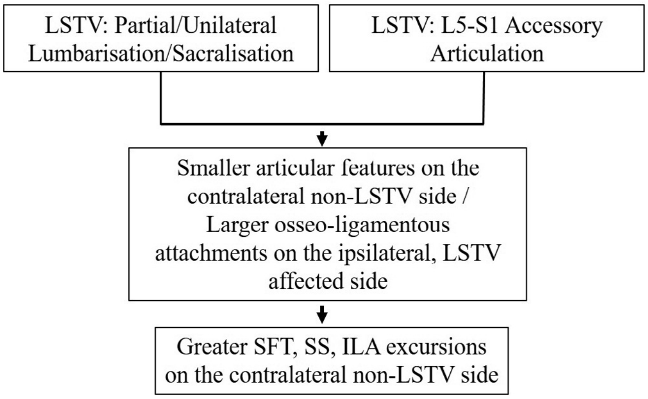

Fig. 2. The schema explaining the anatomical basis of the current hypotheses. Regardless of the increased dynamicity of the non-LSTV side and/or the left/right presentation of the dysfunction, any associated pain may originate from either/both sides.

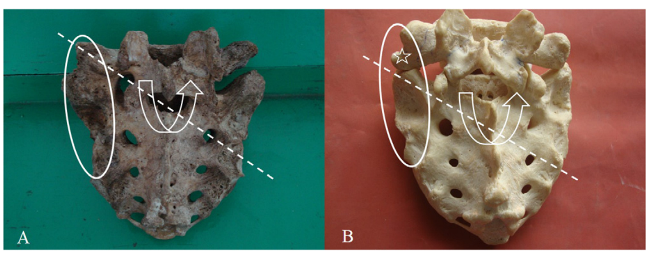

Fig. 3. Representative images from the two unilateral LSTVs discussed in this hypothesis. **A**. Partial/Unilateral sacralisation showing the circled LSTV affected side. The opposite non-LSTV side is relatively unstable allowing greater flexion–extension or torsional excursions . The hypothesis predicts the torsional axis (dashed line) to be ipsilateral to the LSTV allowing backward-forward torsional dysfunction (curved arrow) predominantly on the non-LSTV side. **B**. L5-S1 Accessory Articulation (circled) . The opposite non-LSTV side may be relatively unstable allowing greater flexion–extension or torsional excursion . The hypothesis proposes the torsional axis (dashed line) to be ipsilateral to the side of the LSTV that permits backward-forward torsional dysfunction (curved arrow) predominantly on the unaffected, contralateral, non-LSTV side. Regardless of the increased dynamicity of the non-LSTV side and/or the left/right presentation of the dysfunction, reported pain may originate from eother side. Pain in situation such as in B is usually reported at the site of the accessory articulation (open asterisk).

'vulnerable' to dysfunctions earlier than the ipsilateral LSTV side due to this hypermobility. Therefore, the non-LSTV side may be the side presenting with greater degrees of flexion–extension or torsional excursions if not stabilized by outgrowth of osteophytes, as evidenced by some studies [26,27]. The predicted outcomes of specific tests have been tabulated [Table 1] and features of the hypothesis related to dynamic clinical examination are enumerated below:

(i) Seated Flexion Tests (SFT): SFT or the seated forward flexion test is used to assess decreased motion at one of the sacroiliac joints performed in the seated position. The examiner has a hand on each of the patient's posterior superior iliac spines (PSIS). Next, the patient bends forward while the examiner compares the movement of each PSIS. A test is positive when greater superior motion is felt on one PSIS compared to the other. SFTs may be prominently elicited on the unaffected, non-LSTV side of the SIJ due to the potential hypermobility resulting from the contralateral fusion. Accordingly, in a LSTV-associated back pain patient, dysfunction may be more readily detected on the normal side in the pelvis. In cases of a bilateral flexion–extension or torsional dysfunctions, the SFT values may be greater on the non-LSTV side; or when compared to a similar dysfunction in a patient without such LSTV.

(ii) The Sacral Sulcus (SS): In general, the palpatory depth of the sacral sulcus in sacroiliac dysfunctions can be predicted to be greater or lesser depending on the type and side of dysfunction. However, with partial LSTV, relatively greater laxity at the non-LSTV side may change the palpatory position of the sacral sulcus. Since the side of the LSTV presents a larger sacral auricular area, the ipsilateral joint may be more stable due to the fusion of the L5 element. The SS, therefore, may present deeper on the joint ipsilateral to the LSTV.

(iii) The Infro-lateral Angle (ILA): This test is carried out in the prone position where the examiner palpates the sacral sulcus and the inferior angle of the sacrum on each side. The sacral sulci and inferior angles are assessed to detect if they are symmetrical or asymmetrical. Forward and backward sacral torsions are assessed by noting the excursions of the sacral sulci and the inferior angles having patient move up onto his/her elbows in the same prone position. The side with the smaller SIJ and smaller, less extensive ligamentous attachments may demonstrate larger excursions of the ILA compared to the contralateral side depending on the type of dysfunction. Therefore, SIJ with strong ligamentous attachments (non-LSTV) may demonstrate smaller ILAs and vice versa.

(iv) The Spring Test (ST): In torsional dysfunctions, the axis of rotation identified by palpatory compressive techniques over the pronated sacrum is usually represented by the side with the larger auricular surface area (Fig. 3). The side of the SIJ with larger articular surface is more stable and may force a large swinging arc toward the opposite joint. Additionally, the Spring test may yield greater manual displacement over a smaller, asymmetric, SIJ in extension and in backward torsional dysfunctions. Therefore, the LSTV-related SIJ may represent the rotatory axis of the torsional dysfunction, whereas the contralateral, non-LSTV side may demonstrate greater displacements with the ST.

B. Unilateral L5-S1 accessory articulation (*Castellvi Type IIA*): The common *Castellvi Type IIA* anomaly presents a cartilaginous di-arthrodial articulation between one of the transverse processes of the L5 vertebra with the sacral alae. Unlike partial sacralization, the accessory articulation does not fuse with the sacral ala to augment the ipsilateral auricular surface area [13]. The lumbosacral and ilio-lumbar ligaments demonstrate strong attachments on the ipsilateral, LSTV affected side. Consequentially, the movement at the LSTV-affected SIJ may become restricted and at times, painful [28–30]. These changes may influence outcomes of side-bending and rotation tests. The predicted outcomes [Table 2] and salient features for the tests are described next. The example used in the hypothesis assumes a left-sided Type IIA LSTV that forces the L5 (*in vivo*) to take a slightly left side-bent position (sacral axis shifted to the left). LSTV literature also indicates that these anomalies are associated with facet asymmetries [31,32]. The facets closer to the accessory articulations are found to be smaller (even rudimentary), allowing a greater arc of rotation at the contralateral, non-LSTV SIJ. Therefore, in our example we will consider the L5 to be fixed and rotated slightly to the left. Based on these conditions, the outcomes of clinical tests may be explained in a left accessory-articulated, partial LSTV.

(i) Seated Flexion Tests (SFT): SFTs may be prominent on the non-LSTV side due to the potential hypermobility predicted due to the absence of greater osseo-ligamentous restrainers on this side. Accordingly, although pain may be reported from the side bearing the accessory LSTV articulation, paradoxically, the dysfunction may be detected on the contralateral, non-LSTV SIJ due to the resultant hypermobility.

(ii) The Sacral Sulcus (SS): The depth of the sacral sulcus may be greater or shallower depending on the type and side of dysfunction. However, the sacral articulation contralateral to the accessory LSTV may demonstrate greater mobility for palpatory signs for dysfunction e.g., the depth of the of the sacral sulcus or the position of the sacral base, since the SIJ ipsilateral to the L5-S1 accessory articulation is usually stable and less mobile.

(iii) The Infro-Lateral Angle (ILA): The side contralateral to the LSTV presents less intensive ligamentous attachments compared to the more stable ipsilateral side with the LSTV. Such anatomical discrepancy may feature larger excursions of the ILA at the contralateral, non-LSTV side, depending upon the type of dysfunction detected.

(iv) The Spring Test (ST): In torsional dysfunctions in L5-S1 accessory articulation LSTVs, the axis of rotation is may be represented by the side affected by the LSTV anomaly. This may occur secondary to the 'fixation' of the joints with stronger and abundant osseo-ligamentous connections. Therefore, the SIJ on the LSTV side may be more stable. This side may act as the axis of rotation/torsion of the sacrum and thus, determine the rotational orientation of the lumbosacral joint. This assumption is reinforced by observations in the literature on the facet tropism and lumbosacral movement data that indicate minimization of ipsilateral sacroiliac rotational motion at lumbosacral junctions with partial/incomplete LSTV [21,22,27]. Accordingly, the ST may yield greater manual displacement over the normal, non-LSTV side in extension and backward torsional dysfunctions with asymmetric, unilateral LSTV fusions.

Consequences of the hypothesis and discussion

Morphological and biomechanical data available from studies objectively point out potential etiological implications of LSTV in LBP. Consequently, correct interpretation of the clinical assessment outcomes of sacral dysfunctions associated with LSTV patients may help in accurate diagnosis and clinical decision-making in such cases [3,9,31]. Since a large percentage of LSTV may eventually manifest as lumbosacral disc degeneration and SIJ dysfunction, clinical (and radiological) detection LSTV anomalies may be helpful in customizing specific LSTV related management. This hypothesis proposes the evaluation of mechanistic links and the interpretation of clinical tests results in unilateral LSTV. As postulated in this hypothesis, the oucomes of these tests may appear paradoxical in terms of unexpected fixation of the sacral axis, relative right-left motion discrepancies in the unilateral sacralization / lumbarization scenario. The observations presented on common LSTV asymmetries may help to develop specific manual techniques to detect partial/unilateral LSTV. The hypothetical differences presented in this study may help to explain bio-mechanistic relationship between complex LSTV anatomy, anomalous SIJ motion and LBP. As a future direction, this hypothesis may be confirmed by studying back pain patients, with or without unilateral LSTV, presenting to clinics suggestive of SIJ dysfunction. A single, blinded examiner could perform all the tests described here across patients with normal or LSTV associated SIJ anatomy. Given the current estimates of LSTV prevalence, the high predictive values of the select tests to detect sacral dysfunctions (specificity/sensitivity), and the high probability of positive findings in dysfunction related LBP, a reasonable number of dysfunctional patient cohort would be required to demonstrate an acceptable odds ratio to satisfactorily correlate the predicted outcomes physical exam findings and the LSTV variants discussed in this hypothesis.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.mehy.2019.02.002.

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