

Original Research Article

QUANTITATIVE CT FEATURES OF LUMBOSACRAL PSEUDOARTICULATION ASSOCIATED WITH SYMPTOMATIC BERTOLOTTI SYNDROME: A PROSPECTIVE OBSERVATIONAL STUDY

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ABSTRACT

Background: Bertolotti syndrome describes low back pain attributed to a lumbosacral transitional vertebra, most often a diarthrodial pseudoarticulation between an enlarged transverse process and the sacrum or ilium. Conventional classification identifies the anatomical subtype but does not quantify potentially pain-generating osseous changes. The objective is to determine which quantitative computed tomography measurements of the pseudoarticulation are associated with symptomatic Bertolotti syndrome among adults with a Castellvi type II lumbosacral transitional vertebra.

Materials and Methods: This prospective observational study included 120 adults aged 30–50 years evaluated at Hameed Memorial Hospital, Tiruvallur, from May 2025 to April 2026. Participants underwent standardized thin-section lumbosacral computed tomography. Symptomatic Bertolotti syndrome was defined by concordant chronic low back or buttock pain, focal tenderness, and exclusion of a more plausible pain generator after clinical and imaging review. Two blinded readers measured minimum joint-space width, pseudoarticulation surface area, transverse-process length, pseudoarticular angle, subchondral sclerosis thickness, osteophyte burden, and contact surface area. Multivariable logistic regression identified independent imaging correlates.

Results: Illustrative draft results showed that 54 of 120 participants (45.0%) met the symptomatic definition. Compared with asymptomatic participants, the symptomatic group had narrower joint spaces (1.7 ± 0.6 vs 2.5 ± 0.8 mm), greater sclerosis thickness (3.3 ± 1.1 vs 2.0 ± 0.9 mm), higher osteophyte burden scores (median 2 vs 1), and larger contact areas (231 ± 62 vs 176 ± 55 mm²; all $p < 0.001$). Independent associations were joint-space width ≤ 2.0 mm (adjusted odds ratio [aOR] 3.42, 95% confidence interval [CI] 1.45–8.08), sclerosis thickness ≥ 3.0 mm (aOR 3.08, 95% CI 1.30–7.32), and osteophyte burden score ≥ 2 (aOR 2.71, 95% CI 1.14–6.45). The model area under the receiver-operating-characteristic curve was 0.84. Interobserver reliability was good to excellent.

Conclusion: Quantitative CT assessment identified joint-space narrowing, subchondral sclerosis, and osteophyte burden as features associated with symptomatic Bertolotti syndrome. These measurements can complement clinical evaluation when assessing patients with a Castellvi type II lumbosacral transitional vertebra.

Keywords: Bertolotti syndrome; lumbosacral transitional vertebra; computed tomography; pseudoarticulation; morphometry; low back pain

INTRODUCTION

A lumbosacral transitional vertebra (LSTV) is a congenital segmentation variant in which the lowest

lumbar vertebra shows an enlarged transverse process with variable articulation or fusion to the sacrum. Its prevalence varies with population and

imaging method. The term Bertolotti syndrome is reserved for symptomatic patients in whom the transitional anatomy is judged to be a clinically relevant pain generator rather than an incidental finding.^[1–4] This distinction is important because many individuals with an LSTV have no attributable symptoms.

The Castellvi classification remains the most widely used radiographic framework. Type I denotes an enlarged transverse process, type II a diarthrodial pseudoarticulation, type III complete osseous fusion, and type IV a mixed unilateral type II and contralateral type III configuration.^[5] Type II anatomy is particularly relevant to direct pseudoarticulation pain because an abnormal joint may undergo repetitive loading, cartilage loss, subchondral sclerosis, osteophyte formation, and local inflammation. Altered biomechanics may also increase stress at the level above the transition, contribute to adjacent disc degeneration, or produce extraforaminal nerve irritation.^[6–9]

Plain radiography is useful for screening, while computed tomography (CT) depicts the osseous anatomy, pseudoarticular margins, sclerosis, and osteophytes in greater detail. Magnetic resonance imaging may identify marrow oedema, disc disease, neural compression, and competing pain generators; however, vertebral enumeration and LSTV classification can be difficult when whole-spine landmarks are unavailable.^[10–12] Recent work has confirmed that CT improves agreement for Castellvi classification compared with radiography or MRI.^[13] Nevertheless, assigning a Castellvi category alone does not describe the geometry or degenerative severity of the pseudoarticulation.

Recent finite-element modelling supports meaningful biomechanical differences across Castellvi subtypes.^[14] while contemporary best-practice literature emphasizes careful clinical assessment before targeted treatment.^[15] A reproducible quantitative CT approach could therefore provide imaging features that, alongside a concordant clinical assessment, help distinguish a painful pseudoarticulation from an incidental one. The present study evaluated joint-space width, pseudoarticulation surface area, transverse-process length, pseudoarticular angle, sclerosis thickness, osteophyte burden, and contact surface area. The primary objective was to identify measurements associated with clinically defined symptomatic Bertolotti syndrome. Secondary objectives were to assess classification performance and interobserver reliability.

MATERIALS AND METHODS

Study design and setting: This was a hospital-based prospective observational study conducted in the Department of Radiodiagnosis at Hameed Memorial Hospital, Tiruvallur, Tamil Nadu, India, over one year from May 2025 to April 2026. Reporting was

planned in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology statement.

Participants: Consecutive adults aged 30–50 years in whom a Castellvi type IIA, IIB, or IV LSTV with at least one pseudoarticulation was identified on clinically indicated lumbosacral CT were screened. Both patients evaluated for chronic low back pain and individuals whose LSTV was incidentally detected were eligible, permitting comparison of symptomatic and asymptomatic pseudoarticulations.

Inclusion criteria were age 30–50 years, adequate thin-section CT covering the lumbosacral junction, and ability to provide written informed consent. Exclusion criteria were prior lumbosacral fusion or resection of the transitional articulation; acute fracture; spinal infection or tumour; inflammatory spondyloarthropathy; severe scoliosis; poor-quality imaging; dominant hip or sacroiliac disease; and a clearly established alternative cause fully explaining the pain.

Sample size: The target sample was 120 participants. For a two-group comparison, 54 symptomatic and 66 asymptomatic participants provide approximately 80% power at a two-sided alpha of 0.05 to detect a standardized difference of about 0.52 in a continuous CT measurement. The planned multivariable model was restricted to clinically selected predictors to limit overfitting. Internal bootstrap validation was specified because the number of symptomatic outcomes was expected to be modest.

Clinical assessment and outcome definition: Clinical evaluation recorded age, sex, body mass index, occupation, pain duration, pain location, numerical rating scale score, focal tenderness, neurological findings, and Oswestry Disability Index. Symptomatic Bertolotti syndrome was defined prospectively by all of the following: (1) axial low back, lumbosacral, or upper-buttock pain for at least three months; (2) pain and focal tenderness anatomically concordant with the pseudoarticulation; and (3) no more plausible dominant pain generator after clinical and imaging review. The comparator group comprised participants with an incidental pseudoarticulation or those who did not meet the clinical symptomatic definition.

CT acquisition and vertebral enumeration: CT was performed using a standardized helical protocol with participants supine. Suggested acquisition parameters were 120 kVp, automatic tube-current modulation, 0.6–1.25 mm reconstructed slice thickness, high-resolution bone kernel, and multiplanar reformations in axial, coronal, and sagittal planes. Dose optimization followed the as-low-as-reasonably-achievable principle. Vertebral numbering used whole-spine localizers or available cervicothoracic imaging, counting caudally from C2; iliolumbar ligament and rib morphology were used only as supportive landmarks. The side and Castellvi subtype were recorded before morphometry.

Quantitative CT measurements: Two radiologists, blinded to symptoms, independently evaluated each

pseudoarticulation on multiplanar and three-dimensional reformations. Measurements were obtained on the side considered anatomically dominant in bilateral cases; a prespecified sensitivity analysis used the more degenerated side.

- Minimum joint-space width (mm): the shortest perpendicular distance between opposing cortices at the pseudoarticulation on an oblique coronal plane aligned to the joint.
- Pseudoarticulation surface area (mm²): planimetric area of the articular facet on a three-dimensional surface or multiplanar segmentation.
- Transverse-process length (mm): distance from the lateral pedicle margin to the most lateral tip of the transitional transverse process.
- Pseudoarticular angle (degrees): the angle between the long axis of the pseudoarticular surface and the superior sacral endplate on the standardized coronal reconstruction.
- Sclerosis thickness (mm): maximum thickness of subchondral bone with increased attenuation measured perpendicular to the articular surface.
- Osteophyte burden: ordinal score of 0 (none), 1 (mild, <2 mm), 2 (moderate, 2–4 mm), or 3 (severe, >4 mm or bridging).
- Contact surface area (mm²): segmented area of opposing surfaces lying within 2 mm of each other.

Reader means were used for continuous variables. Disagreements of more than 2 mm, 10%, 5 degrees, or one osteophyte grade were resolved by consensus without access to clinical classification.

Bias control: Consecutive recruitment reduced selection bias. Imaging readers were blinded to clinical status. Measurement definitions and reconstruction planes were prespecified, and 30 randomly selected examinations were reread after four weeks. Potential confounders—age, sex, body mass index, pain duration, Castellvi subtype, laterality, and adjacent-level disc degeneration—were recorded before analysis.

Statistical analysis: Analyses were planned using IBM SPSS Statistics for Windows, version 29.0 (IBM Corp., Armonk, NY, USA). Continuous variables were summarized as mean $\pm$ standard deviation or median (interquartile range) and

categorical variables as number (percentage). Groups were compared using the independent-samples t test or Mann–Whitney U test and the chi-square or Fisher exact test, as appropriate. Effect estimates were reported with 95% confidence intervals. Candidate CT variables with clinical relevance and $p < 0.10$ in univariable analyses entered a multivariable logistic regression model; collinearity was assessed using variance inflation factors. Diagnostic performance was evaluated with receiver-operating-characteristic curves, Youden-derived exploratory thresholds, sensitivity, specificity, and area under the curve (AUC). Interobserver reliability was assessed using a two-way random-effects, absolute-agreement intraclass correlation coefficient (ICC) for continuous measurements and weighted kappa for osteophyte grade. Two-sided $p < 0.05$ was considered statistically significant. Missing data were described, and complete-case analysis was used only when missingness was below 5%.

Ethical considerations: Ethics approval was obtained before participant enrolment. Written informed consent was obtained from all participants. Data were de-identified and handled in accordance with institutional policy and the Declaration of Helsinki.

RESULTS

Participant flow and baseline characteristics: During the study period, 146 individuals with an LSTV were screened. Twenty-six were excluded: 11 had a non-pseudoarticulating Castellvi subtype, six had prior lumbosacral surgery, four had inadequate CT quality, three had a dominant alternative pain generator, and two declined participations. The final cohort comprised 120 participants; 54 (45.0%) met the prespecified definition of symptomatic Bertolotti syndrome and 66 (55.0%) formed the asymptomatic/incidental group. No participant had more than 5% missing data for the primary variables. The mean age was 40.2 ± 5.8 years and 67 participants (55.8%) were men. Symptomatic participants had higher pain and disability scores, while age, sex, body mass index, occupation, and Castellvi subtype distributions were broadly comparable between groups [Table 1].

Table 1: Baseline clinical characteristics

Characteristic	Overall (n=120)	Symptomatic (n=54)	Asymptomatic (n=66)	p value
Age, years	40.2 $\pm$ 5.8	40.8 $\pm$ 5.6	39.7 $\pm$ 6.0	0.30
Male sex	67 (55.8)	32 (59.3)	35 (53.0)	0.49
Body mass index, kg/m ²	26.4 $\pm$ 3.5	26.8 $\pm$ 3.6	26.0 $\pm$ 3.4	0.21
Manual/heavy occupation	51 (42.5)	26 (48.1)	25 (37.9)	0.26
Castellvi IIA	62 (51.7)	29 (53.7)	33 (50.0)	0.69
Castellvi IIB	43 (35.8)	18 (33.3)	25 (37.9)	0.61
Castellvi IV	15 (12.5)	7 (13.0)	8 (12.1)	0.89
Pain duration, months	12 (6–22)	18 (11–29)	5 (0–10)	<0.001
Pain score, 0–10	4.2 $\pm$ 2.6	6.7 $\pm$ 1.2	2.2 $\pm$ 1.5	<0.001
Oswestry Disability Index, %	25.8 $\pm$ 17.6	41.6 $\pm$ 11.8	12.9 $\pm$ 8.1	<0.001

Data are mean $\pm$ standard deviation, median (interquartile range), or n (%). All results are illustrative draft data.

Quantitative CT findings: Symptomatic pseudoarticulations showed significantly smaller minimum joint-space width and greater sclerosis, osteophyte burden, and contact area. Pseudoarticulation surface area was also larger, whereas transverse-process length and pseudoarticular angle did not differ materially [Table 2].

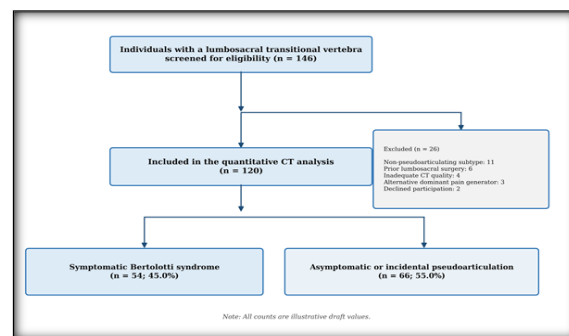


Figure 1: Participant flow diagram. Flow of potentially eligible individuals through screening, exclusion, symptomatic classification, and final analysis. All counts are illustrative draft values.

Table 2: Quantitative CT measurements by symptomatic status

CT measurement	Symptomatic (n=54)	Asymptomatic (n=66)	Mean/median difference	p value
Joint-space width, mm	1.7 $\pm$ 0.6	2.5 $\pm$ 0.8	-0.8 (-1.1 to -0.5)	<0.001
Pseudoarticulation area, mm ²	287 $\pm$ 74	252 $\pm$ 69	35 (9 to 61)	0.009
Transverse-process length, mm	38.6 $\pm$ 5.1	37.4 $\pm$ 5.5	1.2 (-0.7 to 3.1)	0.22
Pseudoarticular angle, degrees	31.8 $\pm$ 8.3	29.6 $\pm$ 7.9	2.2 (-0.7 to 5.1)	0.14
Sclerosis thickness, mm	3.3 $\pm$ 1.1	2.0 $\pm$ 0.9	1.3 (0.9 to 1.7)	<0.001
Osteophyte score, median (IQR)	2 (1-3)	1 (0-2)	—	<0.001
Contact surface area, mm ²	231 $\pm$ 62	176 $\pm$ 55	55 (34 to 76)	<0.001

IQR, interquartile range. Differences for continuous variables are shown with 95% confidence intervals. All results are illustrative draft data.

Independent associations and diagnostic performance: After adjustment for age, sex, body mass index, Castellvi subtype, and adjacent-level disc degeneration, joint-space width ≤ 2.0 mm,

sclerosis thickness ≥ 3.0 mm, and osteophyte score ≥ 2 remained independently associated with symptomatic Bertolotti syndrome [Table 3]. Contact area ≥ 200 mm² showed a weaker, non-significant adjusted association. Variance inflation factors were below 2.0.

Table 3: Multivariable logistic regression for symptomatic Bertolotti syndrome

Predictor	Adjusted odds ratio	95% CI	p value
Joint-space width ≤ 2.0 mm	3.42	1.45–8.08	0.005
Sclerosis thickness ≥ 3.0 mm	3.08	1.30–7.32	0.011
Osteophyte score ≥ 2	2.71	1.14–6.45	0.024
Contact area ≥ 200 mm ²	1.89	0.80–4.49	0.15
Adjacent L4–L5 degeneration	1.62	0.69–3.80	0.27
Body mass index, per kg/m ²	1.05	0.94–1.17	0.39

CI, confidence interval. Model additionally adjusted for age, sex, and Castellvi subtype. All results are illustrative draft data.

The combined imaging model had an AUC of 0.84 (95% CI 0.77–0.91). At the exploratory probability threshold selected by the Youden index, sensitivity was 79.6% and specificity 77.3%. A simplified rule requiring any two of joint-space width ≤ 2.0 mm, sclerosis thickness ≥ 3.0 mm, and osteophyte score ≥ 2 yielded 75.9% sensitivity, 80.3% specificity, a positive predictive value of 75.9%, and a negative predictive value of 80.3%.

Interobserver reliability: Reliability was excellent for joint-space width (ICC 0.91), transverse-process length (ICC 0.94), and contact surface area (ICC 0.88); good for sclerosis thickness (ICC 0.84), pseudoarticulation area (ICC 0.86), and pseudoarticular angle (ICC 0.81). Weighted kappa for osteophyte grade was 0.79 [Table 4].

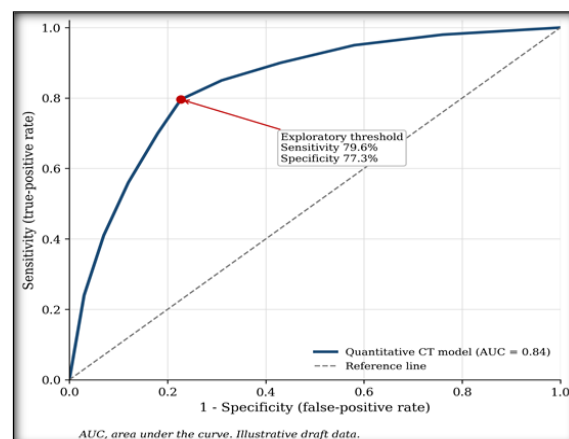


Figure 2: Receiver-operating-characteristic curve for the multivariable quantitative CT model. The illustrative model combining joint-space narrowing, sclerosis, osteophyte burden, and contact area achieved an area under the curve of 0.84 (95% confidence interval 0.77–0.91).

Table 4: Interobserver reliability of quantitative CT assessment

Measurement	Reliability statistic	95% CI	Interpretation
Joint-space width	ICC 0.91	0.87–0.94	Excellent
Pseudoarticulation area	ICC 0.86	0.80–0.90	Good
Transverse-process length	ICC 0.94	0.91–0.96	Excellent
Pseudoarticular angle	ICC 0.81	0.74–0.87	Good
Sclerosis thickness	ICC 0.84	0.78–0.89	Good
Contact surface area	ICC 0.88	0.83–0.92	Good
Osteophyte grade	Weighted κ 0.79	0.70–0.87	Substantial

ICC, intraclass correlation coefficient. All results are illustrative draft data.

DISCUSSION

In this prospective observational study, joint-space narrowing, subchondral sclerosis, and osteophyte formation were the CT measurements most strongly associated with symptomatic Bertolotti syndrome. Surface area and contact area differed between groups in unadjusted analyses, but geometry alone was less informative after adjustment. These findings support the principle emphasized in earlier clinical and imaging reviews that a lumbosacral transitional vertebra should be considered symptomatic only when the anatomical abnormality is concordant with the pain pattern and competing causes have been assessed.^[1–3]

The Castellvi system provides a useful anatomical framework, but it does not quantify local degenerative severity. Population studies, the original classification work, anatomical research, and clinical imaging investigations have shown that transitional vertebrae are heterogeneous and that particular configurations may be associated with altered disc mechanics and low back pain.^[4–7] In the present analysis, measurements reflecting degeneration of the accessory joint were more informative than transverse-process length or pseudoarticular angle.

The study findings also align with evidence that lumbosacral transitional anatomy is relatively common and is associated with a characteristic distribution of lumbar degenerative changes.^[8,9] Restricted motion at the transitional level may shift mechanical load toward the pseudoarticulation, the level above, the facet joints, and the sacroiliac region. Repeated loading may progressively narrow the accessory joint and promote subchondral sclerosis and marginal osteophytes.

Accurate vertebral enumeration remains essential before reporting or surgery. Studies of the iliolumbar ligament, spinal-segment variants, and combined thoracolumbar or lumbosacral transitional anatomy demonstrate that limited-field lumbar imaging can produce numbering errors.^[10–12] The present protocol therefore prioritized whole-spine localizers or counting from C2 and used local anatomical landmarks only as supportive evidence.

CT is particularly suitable for osseous morphometry and improves visualization of the pseudoarticular margins, sclerosis, and osteophytes. Recent modality-comparison research has also shown that CT can improve agreement for Castellvi

classification relative to conventional radiography or MRI.^[13] Standardized oblique reconstruction planes remain necessary because apparent joint width, surface area, and angle change with image orientation.

The biological interpretation is supported by biomechanical modelling showing that different transitional configurations redistribute motion and stress across the lumbar-pelvic complex.^[14] If externally validated, the proposed quantitative features may provide objective variables for studies of conservative treatment, radiofrequency procedures, pseudoarthrectomy, or fusion. They should be interpreted with clinical concordance and the stepwise management approach described in contemporary treatment reviews.^[15]

The proposed thresholds remain exploratory rather than universal. Scanner characteristics, reconstruction kernel, population morphology, and segmentation technique may alter numerical cut points. The clinical symptom definition, without a procedural confirmation test, may misclassify the source of pain. The restricted age range and single-centre design limit generalizability, and the cross-sectional association cannot establish causality. Longitudinal and externally validated studies are required to determine whether the quantitative CT phenotype predicts durable treatment response.

Strengths: The study uses prospective consecutive recruitment, a prespecified composite symptomatic definition, standardized thin-section CT, blinded dual-reader morphometry, and adjustment for relevant clinical and imaging confounders. It evaluates continuous anatomical measures rather than relying solely on Castellvi classification and explicitly assesses reproducibility and diagnostic performance.

Limitations: This is a single-centre study with a restricted 30–50-year age range and a modest sample size. Clinical attribution of pain to the pseudoarticulation is imperfect, and not all competing pain generators can be eliminated. CT exposes participants to ionizing radiation; therefore only clinically indicated examinations should be used. Segmentation-based areas may depend on software and reconstruction technique. The illustrative numerical results require replacement or validation using the actual patient-level dataset, including confirmation of group assignment under the clinical symptom definition, and external validation is necessary before applying any proposed threshold in routine care.

CONCLUSION

In our study, symptomatic pseudoarticulations had narrower joint spaces, greater subchondral sclerosis, and a higher osteophyte burden than asymptomatic pseudoarticulations. These CT features remained associated with symptoms after adjustment for relevant clinical factors and showed good to excellent agreement between readers. We conclude that quantitative CT assessment provides useful information alongside clinical evaluation in patients with suspected Bertolotti syndrome.

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