Vertebrae at the thoracolumbar junction: A quantitative assessment using CT scans

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Abstract

The thoracolumbar junction is often associated with traumatic injuries, due to its biomechanical instability. Reasons for this instability are currently still under debate; however, contributing factors such as the rapid change in spinal curvature and facet orientation from the thoracic to lumbar transition have been implicated. Normally, the superior facet orientation in the thoracic region is angled in a coronal plane, whereas vertebrae in the lumbar region have facets angled in the sagittal plane. Distinguishing between thoracic, lumbar, and transitional vertebrae at the thoracolumbar junction based on articular facet angles, using quantitative methods on CT scans has, to the authors' knowledge, not yet been reported in the literature. Therefore, this study aimed to evaluate whether quantitative measurements can be clinically applied and used to differentiate vertebrae at the thoracolumbar junction using CT scans and, additionally, to record possible cases of congenital defects or variations observed in the spine. A sample (*n* = 173) of CT scans representative of the Windhoek population in Namibia was retrospectively assessed using radio-imaging software. Measurements of the angle formed by the superior facets of the vertebrae at the thoracolumbar junction (T11-L1) were recorded. Based on the results of this study, quantitative morphometry of the superior facet of vertebrae can differentiate between thoracic, lumbar,. and transitional vertebrae at the thoracolumbar junction. All individuals with identified thoracolumbar transitional vertebrae (TLTV) in this sample had at least one other congenital anomaly of the spine.

Keywords: congenital defects, transitional vertebra, vertebral column

1 INTRODUCTION

The thoracolumbar junction is a region in the spine with great clinical relevance and functions as an important surgical landmark. It has unique anatomical and biomechanical features that allow the vertebrae to transition between the kyphotic thoracic to the lordotic lumbar region (Piastra & Lucarini, 2018). Although there remains much controversy regarding the exact mechanism, there is speculation that the thoracolumbar junction is a biomechanical weak point in the spine (Beisse, 2006; Kim et al., 2015; McLain, 2006; Shin et al., 2016). Attributing factors such as a rapid change in spinal curvature and facet orientation from the thoracic to lumbar transition have been implicated. It has been postulated that these biomechanical factors disrupt the axial load and subsequent transmission of weight down the spine to the sacrum (Zaneb et al., 2013). This instability is a common cause of injury and fractures from traumatic insult in the thoracolumbar spine that often require surgical intervention (Kim et al., 2015; McLain, 2006; Piastra & Lucarini, 2018; Zaneb et al., 2013). As the thoracolumbar junction is also the end-point of the spinal cord and start of the corda equine, structural damage of the spinal cord may occur during surgical procedures if the thoracolumbar junction is incorrectly identified. The implications should, therefore, be considered by clinicians during surgical intervention as any deviation from typical vertebral anatomy can result in confusion that may lead to significant clinical errors (Thawait et al., 2012). Therefore, differentiating between vertebrae at the thoracolumbar junction bears much clinical and anatomical significance.

Differentiation of vertebrae between anatomical regions of the spine can be done through assessment of vertebral morphology using radio-imaging modalities (Dias, 2007; Zaneb et al., 2013). (Doo et al., 2020; Lewis et al., 2009; McLain, 2006; Park et al., 2020; Wu et al., 2021). Features that are commonly examined to differentiate between the respective regions include the spinous process, vertebral body, and direction of joint facets along with unique features for each region such as transverse foramina, costal facets or anterior sacral foramina. At the thoracolumbar junction, rib articulation is the primary structure that separates the thoracic region from the lumbar region. It demarcates the thoracolumbar junction that transitions the thoracic region to the adjacent region, the lumbar spine. Costal facets for rib articulation is one of the unique features of all thoracic vertebrae, as it anchors the thoracic cage to the trunk of the body (Carrino et al., 2011; Thawait et al., 2012). The lumbar spine, however, is the primary weight-bearing region of the spine, therefore, large vertebral bodies and mammillary and accessory processes for stabilizing muscle attachment are unique features of this region. Another feature that stands out, with regard to the transition between the thoracic to lumbar region, is the alignment of the superior and inferior articular facets (Bruce C, 2015).

In the thoracic region, the facets are orientated in a coronal plane, whereas vertebrae in the lumbar region have facets orientated in the sagittal plane (McDonald, 2007). A study by Forseen et al. (2015) applied the anatomy of vertebral facets to radio-imaging modalities, stating that facet orientation can be observed on CT scans in order to differentiate between the last thoracic and first lumbar vertebrae. Their findings demonstrated that the thoracic vertebrae typically have superior facets that face posteriorly, whereas lumbar vertebrae facets face medially. The study, however, did not consider that sequencing and classifying of vertebral types in the thoracic region depends on costal articulation. Furthermore, the study also did not demonstrate a significant measurable distinction between the two regions (Bron et al., 2007). Another interesting finding by Forseen et al. (2015) was that the majority (227/244; 93%) of individuals in their study showed an “abrupt” change from the thoracic to lumbar facet orientation and the remaining 7%; a more gradual facet transition from one region to the other.

Vertebrae at the thoracolumbar junction can potentially be either thoracic, lumbar, or thoracolumbar transitional vertebrae (TLTV). Transitional vertebrae are defined as vertebrae that result from overlapping somites resulting in blended regional features of adjacent vertebrae in the spine (Doo et al., 2020; Oostra et al., 2005). Controversy regarding the classification of TLTV however still exists, with some authors rooting their findings by using the articulation of hypoplastic ribs to the vertebra as the identifying feature of TLTV (Carrino et al., 2011; Park et al., 2016a, 2016b). However, this classification was established over 40 years ago by Wigh and Anthony (1981) and more recent investigations have contradicted this statement; recognizing TLTV by its overlapping features of the adjacent regions, specifically thoracic and lumbar regions regardless of the hypoplastic rib association (Du Plessis et al., 2018b). Using overlapping features is already readily applied in transitional vertebrae at the lumbosacral junction (Konin & Walz, 2010; Sekharappa et al., 2014). This updated classification describes the detailed features of transitional vertebrae at the thoracolumbar junction. It also includes TLTV in both the lumbar and thoracic regions, not only vertebrae with costal articulation as previously defined. One of the overlapping features of TLTV identified by Du Plessis et al. (2018b), is the altered facet orientation. The facets are asymmetrical or atypical of vertebrae in that respective region. Interestingly, alterations of auricular surface facets in the sacrum were also proposed in LSTV and implicated as a possible source of lower back pain (Mahato, 2013). Other identifying features of TLTV include hypoplasia of the transverse processes and an atypical mammillary process placement.

To the author's knowledge, no study has quantified a significant statistical distinction between the thoracic and lumbar regions in living persons by measuring the facet angles on radio images at the thoracolumbar junction. The aim of this study was to evaluate whether quantitative measurements can be used to differentiate vertebrae at the thoracolumbar junction in living patients, using computerized tomography (CT) scans. In addition, this study aimed to record cases of congenital defects or variations in the spine observed in the same sample.

2 MATERIALS AND METHODS

2.1 Materials

A random sample ($n = 175$) of digital CT scans, from archives (2018–2020) of the Namibian population in Windhoek, was retrospectively evaluated. This sample size is considered sufficient for a 95% confidence interval and a margin of error of 7% for this population. The CT- scans in the archive were originally taken for diverse pathology in the thorax, abdomen, pelvis, and spine that is not directly related or influenced the inclusion for this study. The sample included a random distribution of adults aged 18–80 years old. Individuals were included in the study if the scans contained an axial view of T10/T11-L1/T12. Patient images diagnosed with severe scoliosis, osteophytes, and trauma by registered radiologists were excluded from the sample (*n* = 24) as it interfered with evaluation of the scans. All patients included in the study sample remained anonymous and a unique identifier number was assigned to each individual.

2.2 Methods

Patient CT scans (*n* = 200) were assessed, from which 25 patients were excluded due to severe scoliosis, osteophytes, and trauma. The rest of the patient scans were included in the sample (*n* = 175). From the sample, 14 patients had identifiable defects in the spine and 161 patients had no discernable defects or pathology and were categorized as normal.

Thoracic vertebrae were differentiated from lumbar vertebrae according to the classification based on rib articulation of (Bron et al., 2007). Therefore, the last vertebra with costal articulation is numbered as the last thoracic segment and the next vertebra without costal articulation is numbered as the first lumbar segment. TLTV was differentiated from other thoracic and lumbar segments based on the atypical orientation of the superior articular facets according to the classification described by Du Plessis et al. (2018). Once the vertebrae were identified, measurements were taken of each respective vertebral type.

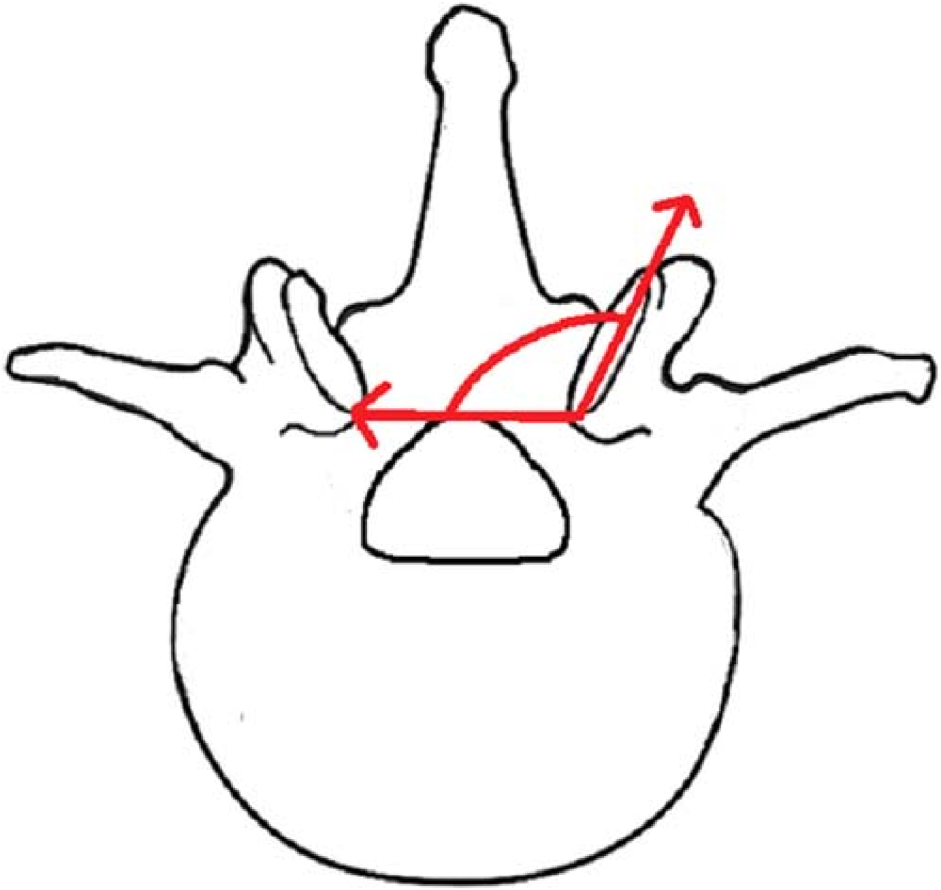

FIGURE 1. Measuring the superior facet

Measurements of the superior facet angles (in degrees) were recorded from the eleventh thoracic (T11) to the first lumbar (L1) vertebra in the sample (*n* = 175). Axial views of scans were rotated until perpendicular superior view of the respective vertebrae was visible for measuring. The angle measured is formed by a line that runs between the two inferior medial points of the superior facets and a line that runs directly parallel to the articular surface of the facet when viewed from above as demonstrated in the example below (Figure 1). The imaging software used, Syngo ® by Sie$270^\circ > y > 180^\circ$t compensate for measurements $y = 360^\circ - x$180°, therefore, all reflex angles ( ) required manual calculations ( ) to determine the angle size of the superior facets, specifically in the thoracic region. All other congenital defects or variations in the spine were recorded, if present.

2.3 Statistical analysis

Pearson's Coefficient of skewness (SK) was used to evaluate the spread of the data based on a symmetrical bell-shaped distribution to determine whether the distribution of the sample falls into normal parameters.

Analyses of variance coupled with Bonferroni's correction test were performed in order to determine whether significant variation in angle sizes exists between normal thoracic and lumbar vertebrae at the thoracolumbar junction. Additional measures of central location were calculated within a margin of error to infer a range of the superior facet angles for each respective vertebral type.

Any congenital abnormalities or relevant pathology was recorded as qualitative observational data.

Interobserver correlation analyses were used to assess the repeatability of this study (*n* = 10). This was done by and asking two objective observers to repeat measurements for this selection. The results were cross referenced with the measurements taken by the primary researcher.

2.4 Ethical considerations

This study was ethically cleared by the Ministry of Health and Social Services in Namibia (17/3/3ADP) as well as by the University of Pretoria's Research Ethics Committee (678/2018). The parameters of this study fall with the requirements set out in the National Health Act 61 of 2003.

2.5 Limitations

The proposed model may be applied to radio images, however, this study has demonstrated that the axial view of the thoracolumbar junction is typically excluded from routine magnetic radio imaging (MRI) scans of the lumbar region. In addition, the distance between the sections is often too large to accurately view the superior facets on each vertebral level. Therefore, this study was limited to the use of digital CT scans, as it allows one to gradually view the vertebral segments of the thoracolumbar junction and adjust the axial view as needed. As the scans were part of an archived CT-scan collection (*N* ± 1000), the scans were originally taken for other unrelated diagnostic purposes and did not necessarily include the entire thoracic or lumbar spine. Majority of the scans included in this study were scans taken of the thoracic region and did not include axial views beyond L1/L2 junction, therefore, the inclusion was limited to (T11-L1). Lumbar CT scans were available in the archive, but very often did not extend to T12/L1 junction, therefore, were not viable.

3 RESULTS

Analyses of variance revealed that there was no significant difference ($p > 0.05$) between the right and left facet orientations in normal T11 ($p = 0.246$), normal T12 ($p = 0.10$), normal L1 ($p = 0.12$) vertebrae. However, a significant difference ($p < 0.0001$) was clearly observed when the facets that interchangeably resemble the thoracic region were compared to the superior facet that resembles the lumbar region in TLTV, regardless of being right or left. In addition, the results show that the mean difference between the facets of T11 was 3.5 ± 2.88° (CI: 3.04–3.95), 3.65 ± 3.06° (CI: 3.18–4.13) in T12 and 4.8 ± 3.85° (CI: 4.19–5.39) in L1. However, in TLTV the mean difference between the facets was 36.5 ± 13.08° (CI: 28.6–44.4) (Table 1). Therefore, the results clearly indicate that TLTV is significantly asymmetrical compared to other vertebral segments at the thoracolumbar junction. Further analyses of variance (ANOVA) confirmed by Bonferroni's corrected test (Table 2) indicated a significant difference between all groups, except between T11 and T12.

TABLE 1. Statistical analyses of the difference between superior facet angles (right and left) for each vertebral type

Descriptive Statistics	T11	T12	L1	TLTV
Mean	3.49689441	3.652173913	4.78882	36.53846
Standard error	0.227756446	0.240867491	0.303628	3.629677
Median	3	3	4	34
Mode	2	3	5	30
Standard deviation	2.889905326	3.056265838	3.852613	13.08699
Sample variance	8.351552795	9.34076087	14.84262	171.2692
Kurtosis	2.402527246	4.300283506	1.878528	−0.34095
Skewness	1.420767244	1.666242113	1.338932	0.777061
Range	15	18	18	41
Minimum	0	0	0	21
Maximum	15	18	18	62
Sum	563	588	771	475
Count	161	161	161	13
Pearson's coefficient (SK)	0.515824244	0.640167395	0.614248	0.581905
Lower bound confidence interval	3.047097849	3.176484329	4.189184	28.63007
Upper bound confidence interval	3.946690971	4.127863497	5.388456	44.44685
Confidence level (95,0%)	0.449796561	0.475689584	0.599636	7.908387

TABLE 2. Analyses of variance between vertebral types

Groups	*p* Value	Test	Alpha
T11 versus T12	0.024260001	ANOVA	0.05
T12 versus L1	0	Bonferonni corrected	0.008333333
T11 versus L1	0		
TLTV versus T11	6.405×10^{-71}		
TLTV versus T12	8.537×10^{-60}		
TLTV versus L1	4.109×10^{-30}		
ANOVA	0		

The data were subsequently pooled for the descriptive summary statistics. The results show that all the groups in the sample (thoracic, lumbar, and TLTV) have a normal distribution, with modest skewness and are, therefore, unbiased. This was determined by calculating the SK values of T11 (SK = +0.2), T12 (SK = +0.8), L1 (SK ≈ +0.14), and TLTV (SK = +0.58). The SK values of all groups fall within acceptable parameters as the SK values of any normal distribution data set fall within the range ($-3 < SK < 3$), see Table 3.

TABLE 3. Statistical analyses of superior facet angles according to each vertebral type at the thoracolumbar junction

Descriptive statistics	T11	T12	L1	TLTV
Mean	184.4503	182.795	112.332298	135.7307692
Standard error	0.455161	0.574515	0.4053521	4.269951429
Median	185	180	112	131.5
Mode	180	178	109	114
Standard deviation	8.16758	10.30931	7.27378344	21.77256566
Sample variance	66.70936	106.2818	52.9079255	474.0446154
Kurtosis	0.537601	−0.31682	−0.00813979	−1.1096557
Skewness	−0.285555	0.638445	0.15752235	0.311240728
Range	47	48	46	74
Minimum	160	161	90	102
Maximum	207	209	136	176
Sum	59393	58860	36171	3529
Count	322	322	322	26
Pearson's coefficient (SK)	−0.201904	0.813352	0.13705308	0.582949566
Lower bound confidence interval	183.5548	181.6647	111.534816	126.9366396
Upper bound confidence interval	185.3458	183.9253	113.12978	144.5248988
Confidence level (95,0%)	0.895476	1.130291	0.79748231	8.794129587

The average angle for normal T11 superior facets was 184.5 ± 8.16° (CI: 183.5–185.3), 182.8 ± 10.4° (CI: 181.6–183.9) for normal T12 superior facet angles, and 112.3 ± 7.27° (CI: 111.5–113) for normal L1 superior facet angles. The TLTV vertebrae interestingly fall into their own category with a mean facet angle of 136 ± 23.18° (CI: 125–147), which places them between the T12 and L1 superior facet angles (Table 3). The fact that the TLTV falls into their own class is further strengthened by the narrow and non-overlapping confidence intervals for all vertebrae groups. However, as mean is only a measure of central location, it is important to consider the variation and range in order to determine the entire distribution of the TLTV compared to the distributions of T11, T12 and L1. The results clearly demonstrate that each vertebral type has a unique distribution placing it into separate categories and that TLTV has a distribution that encompasses a much larger variation, range, and error than normal T11, T12, and L1 segments (Figure 2). The high standard error of TLTV in comparison to the other vertebral types clearly highlights the atypical nature of its morphology.

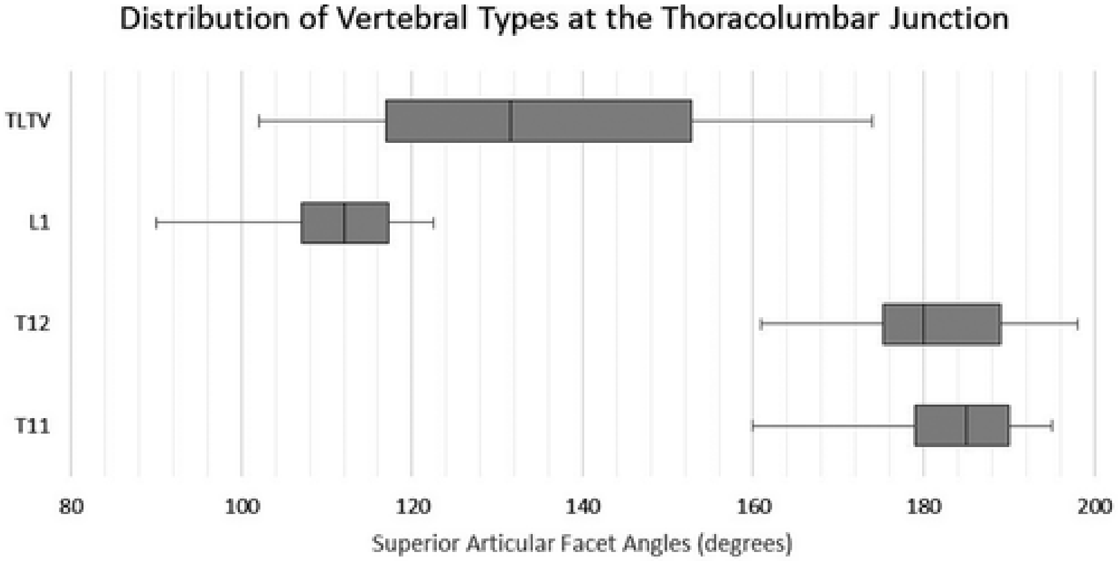

FIGURE 2. Boxplot depicting the distributions of superior facet measurements of T12, L1 and TLTV

High correlation coefficients were demonstrated by the interobserver error analysis (*n* = 10) cross evaluated between three observers (0.978 < r < 0.997).

This study also found that all cases of TLTV (*n* = 14) were associated with at least one other defect or segment variation in the spine (Table 4). Associated anomalies recorded in this study included spina bifida (*n* = 5), hypoplastic ribs (*n* = 8), sacralization (*n* = 4) and numeric variation in the lumbar spine (*n* = 6). Results also showed a high number of individuals with compression fractures in the lumbar spine (*n* = 4).

TABLE 4. Congenital anomalies observed in the sample

	Hypoplastic Ribs	**Fracture surgical fusion**	**Variation in lumbar spine**	**Spina bifida**	**TLTV**	**Sacralization**
1					1	1
2	1				1	
3		1	1		1	1
4		1	1	1	1	
5	1		1		1	
6	1			1	1	
7	1		1	1	1	1
8	1				1	
9		1			1	
10	1			1	1	
11	1	1	1		1	1
12					1	
13	1			1		
14			1		1	
TOTAL	**8**	**4**	**6**	**5**	**13**	**4**

The bold values represent the sum of the defects in each column.

4 DISCUSSION

The results of this study clearly demonstrate that TLTV vertebrae can be accurately identified on CT scans based on the angle of their superior articular facets (Figure 3). The same applies for clinically identifying and distinguishing the lower thoracic (T11 and T12) and the upper lumbar (L1) vertebra from each other as well as from TLTV at the thoracolumbar junction on patient CT scans (Figure 4). This can be done by comparing the variation observed between the measurements of the right and left superior facet of a vertebral segment. No significant differences between the right and left superior facet angles for all normal vertebrae (T11, T12, and L1) were observed. However, the results clearly demonstrate that TLTV is significantly asymmetrical and that one side interchangeably resembles the thoracic region and the other the lumbar region, highlighting the overlap of somites and developmental fields during development.

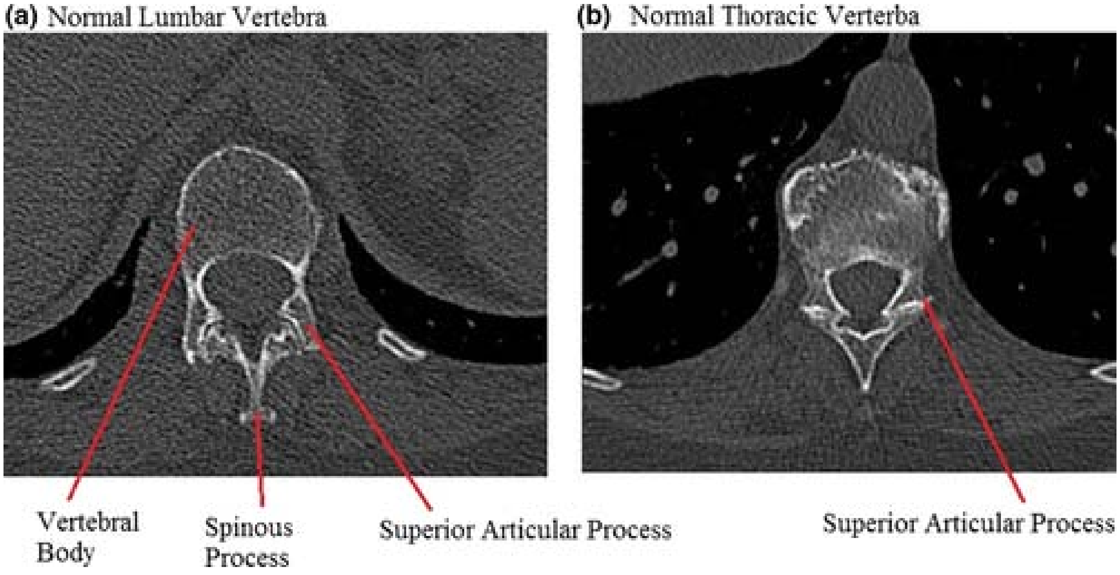

FIGURE 3. CT scan of a normal thoracic (a) and normal lumbar vertebrae (b) demonstrating superior facet orientation and symmetry

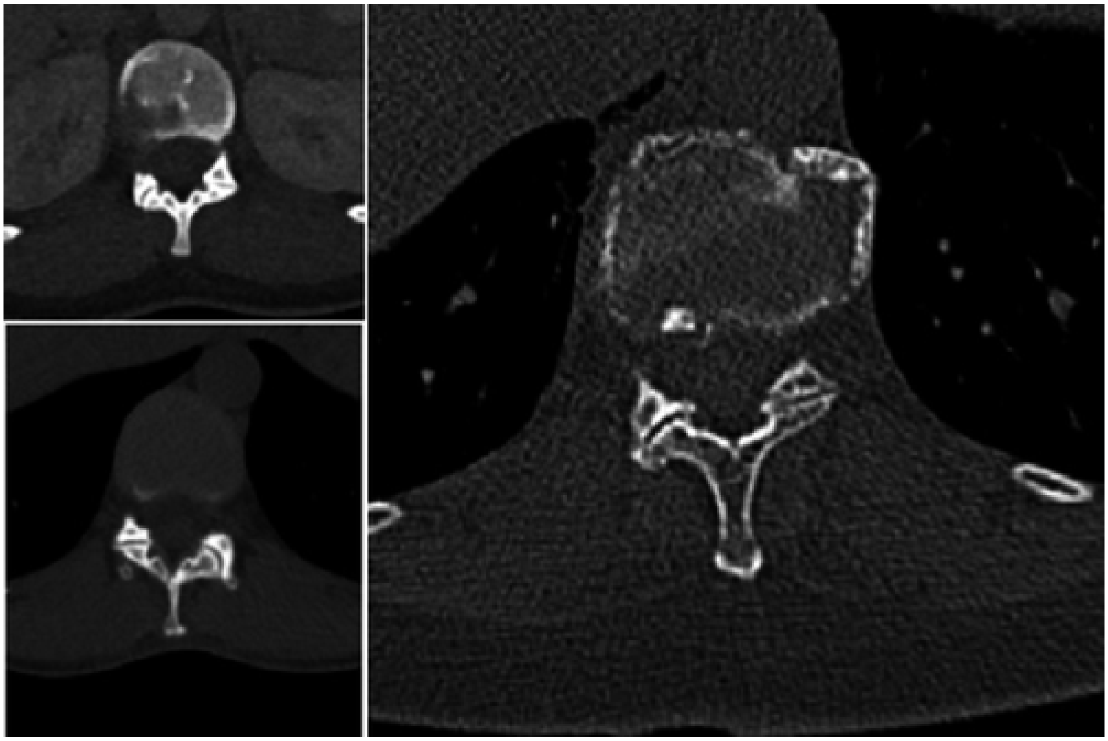

FIGURE 4. Axial CT Scans of TLTV

The second identifiable feature that distinguishes the vertebral type is the measurable distribution. The results clearly demonstrate that each vertebral type falls within its own unique distribution, placing each type into a separate category. From the results, one can also see that TLTV is the only vertebral type that has a distribution with atypically large variation and parameters that extend well within T12, L1 criteria.

In addition, the results show that all cases of TLTV (*n* = 13) were associated with at least one other defect or numeric variation in the spine, see Table 4. These findings corroborate with those reported by Du Plessis et al (Du Plessis, 2018; Du Plessis et al., 2018a) in that there is a clear association between TLTV and specific spinal defects in the Western Cape.

Interestingly, it was observed that seven of the 13 patients with TLTV also had hypoplastic ribs on the last rib bearing segment. This finding is significant as it may explain why researchers have mistakenly classified TLTV according to the corresponding presence of hypoplastic ribs in prior literature. It was seen that five out of the eight patients with hypoplastic ribs, also had numerical segment variation. If the initial interpretation was that numerical variations are a derivative of border shifts and, by extension, transitional vertebrae, it is very possible that hypoplastic ribs could have mistakenly been reported as the identifying feature of TLTV. However, the results from this study show there is merely a high association (*n* = 7/13) between hypoplastic ribs and TLTV. This is most likely due to the common embryological origin of vertebrae and ribs, specifically that both structures are derivatives of the sclerotome (Rawls & Fisher, 2010). It is also noteworthy that TLTV was found at the T12, L1, or in cases of supernumerary T13 segments, both in this and prior studies (Du Plessis et al., 2018b). Finally, hypoplastic ribs do not take into account TLTV located in the lumbar region, as rib articulation is not a feature in the lumbar region.

Additional findings suggest patients with segment variation and TLTV experience decreased biomechanical stability of the spine, as four out of five patients with supernumerary in the lumbar spine had vertebral compression fractures and disc dislocation. The majority of these cases (80%) had surgical intervention in the form of vertebral segment fixation at the lumbosacral junction.

In conclusion, the results from this study strongly infer that quantitative morphometry of the superior facet in vertebrae can differentiate between thoracic, lumbar, and transitional vertebrae at the thoracolumbar junction. Lastly, this study found that all patients with TLTV in this Namibian sample had at least one other congenital anomaly of the spine. These findings are in agreement with previous work that has reported an association in the Western Cape of South Africa (Du Plessis, 2018; Du Plessis et al., 2018a).

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