Original Article

Typical Thoracic Vertebrae Morphometry: A Cadaveric Study in Nigeria

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Abstract

Introduction: Spine morphometry is of global interest because of its great importance in prosthetics, orthopedics, and biomechanics. The present study was carried out to provide a comprehensive morphometric data of typical thoracic vertebrae in Nigeria. **Material and Methods:** A total of 208 typical thoracic vertebrae which consist of 26 set of macerated adult male vertebrae, were studied by direct measurements of the vertebral body, vertebral foramen, pedicle, lamina, spinous and transverse processes, and superior and inferior articular processes. Digital Vernier Caliper was used to measure internal and external distances. Data collected were statistically analyzed and mean values were presented in a mean ± standard deviation. **Results:** Anterior vertebral body height (VBH) gradually increased to a maximum value at T9 (18.83 ± 1.54 mm) and minimum at T2 (16.93 ± 1.57 mm). Mean value of posterior VBH was minimum at T2 (17.59 ± 1.43 mm) and maximum at T9 (20.46 ± 3.08 mm). Width of spinous process tip had relatively stable values from T2 to T9 with the maximum at T2 (5.05 ± 1.36 mm). Lamina thickness mean values were relatively stable from T2 to T9 with a maximum value at T9 level (7.30 ± 1.24 mm) and the minimum at T2 (6.60 ± 1.16 mm). **Discussion and Conclusion:** Superior and inferior articular surfaces and Laminae were reported for the first time which contributes to the novelty of this study. These findings will serve as a guidepost in the understanding and design of well-fitted materials for the typical thoracic vertebrae, which will enhance preclinical and clinical evaluation of vertebral implants, prosthetics, and management of spine pathology.

Keywords: *Morphometry, Nigeria, prosthetics, typical thoracic vertebrae, vertebral dimensions*

Introduction

Successful spinal morphometry has appeared in the medical literature since the 19th century and has been an interesting area for spinal surgical procedures and researchers.[1-4] These morphometric studies have helped in the design of a vast array of implants and surgical approaches. Vertebral morphometry is a quantitative method used to identify osteoporotic vertebral fractures and relies on the measurement of distinct vertebral dimensions, calculating relative changes.[5] Age-related changes in the vertebrae morphometry are important in detecting vertebral fractures and degenerative shape changes,[6] also different biomechanical loading and deformation conditions for segments of vertebrae; thoracic and lumbar segments, as they are subjected to dissimilar compression forces. This creates the need to analyze the segments of the vertebrae separately, and no study has critically and comprehensively assessed the morphometric features of the typical thoracic vertebrae in Nigeria.

In general, information regarding the precise dimensions of the typical thoracic vertebrae is essential for spinal surgery and instrumentation. However, few anatomical studies have been performed to determine the criteria and limits of "normal," serving as guidelines in assessing pathological conditions.[7] In surgical procedures, a combination of both biologic (bone graft) and prosthetic (instruments) materials are used to form a construct that aims to maintain spinal stability in an unstable region of the spine.[8] Posterior fixation of the thoracic spine with rods, hooks, and wires has been used successfully to correct deformity and achieve stability in patients who have scoliosis, traumatic injury, or vertebral collapse secondary to infection.[9] Comprehensive assessments of the morphometric features of the vertebrae components are required to guide all of these procedures, including the very delicate ones as they will enhance preclinical evaluation of spinal implants

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and serve as a necessary step to ensure their reliability and safety before implantation.[10]

Furthermore, the shape and size of the thoracic body, pedicles, laminae, vertebral foramen, spinous process, and transverse process of the human spine differ within different races.[5] This has been reported in different races.[11-13] Some studies were conducted on some of the vertebral features,[9,14] but most of these studies were focused mainly on the pedicles of thoracic vertebrae[15-17] whereas there are other very important vertebrae dimensions that also need assessment in different populations.

From prosthetic and orthopedic evaluations, it is obvious that the findings from this study will be a guidepost to understanding the characteristic features of typical thoracic vertebrae. To the best of our knowledge, no detailed morphometric study on the typical thoracic vertebrae has been carried out in Nigeria and surrounding sub-saharan African populations. Therefore, to conclusively establish racial and environment based peculiarities in vertebral dimensions, it is absolutely necessary to carry out a comprehensive and qualitative morphometric study of the typical thoracic vertebrae.

Material and Methods

Ethical approval for this study was obtained from the Ethics/Research Committee of the Faculty of Basic Medical Sciences, Federal University Ndufu-Alike Ikwo. A total number of 208 typical thoracic vertebrae which consist of 26 set of macerated adult male vertebrae were studied. The age of the samples was not identified but generally belonged to adults from the south-south and south-east regions of Nigeria. The bones were processed in the Gross Anatomy Laboratories of Ebonyi State University, University of Nigeria, Cross River University of Technology, University of Calabar; Nnamdi Azikiwe University and Federal University Ndufu-Alike Ikwo; all in Nigeria. The study involved direct measurements for linear dimensions of the vertebral body, vertebral foramen, pedicle, lamina, spinous and transverse processes, superior and inferior articular processes.

Research design

The following parameters were measured.

1. Pedicle [Figure 1]
   - Mid-pedicle width (MPW): The outer cortical transverse distance of the mid-pedicle
   - Pedicle height (PH): The superior-inferior outer cortical width of the pedicle with two sites namely mid pedicle height (MPH) and at the root of the pedicle height (RPH) (junction of pedicle with the vertebral body)
   - Pedicle length (PL): Distance from the posterior cortex of pedicle to the junction of pedicle with the vertebral body in line with the axis of the pedicle
   - Chord length (CL): Measured from the posterior cortical entry point of the pedicle to the anterior vertebral cortex along the axis of the pedicle.
2. Vertebral foramen (canal) [Figure 1]
   - Canal dimension (CD): CDs were measured both in anteroposterior (APD) and interpedicular distance (IPD).
3. Vertebral body [Figure 2]
   - Vertebral body height (VBH): Distance between superior and inferior end plates are were measured both anteriorly (VBHa), vertebral body height midway (VBHm), and posteriorly (VBHp)
   - Vertebral body width (VBW): The width of the vertebral body at superior endplate (VBWs), middle (VBWm), and inferior endplate (VBWi) were measured
   - Vertebral body length (VBL): Distance between the anterior and posterior surface of the vertebral body were measured both superior (VBLs), inferior (VBLi), and middle (VBLm).
4. Transverse process [Figure 1]
   - Length of the transverse process (LTP): Measured from base to tip of the transverse process
   - Width of transverse process at the base (WTPb): Distance between superior and inferior borders of the transverse process at base
   - Width of transverse process at the middle (WTPm): Distance between superior and inferior borders of the transverse process at middle
   - Width of transverse process at the tip (WTPt): Distance between superior and inferior borders of the transverse process at the tip.
5. Spinous process [Figure 1]
   - Length of the spinous process (LSP): Midline junction of the left and right lamina to the tip of the spinous process
   - Width of the spinous process (WSP): Including the base (WSPb), middle (WSPm), tip (WSPt).
6. Lamina [Figure 2]
   - Length of the lamina (LL): To be measured from the junction of the lamina with the pars articularis to the midline where it joins with the other lamina
   - Lamina thickness (LT): Distance between the anterior and posterior surfaces
   - Lamina height (LH): Distance between the superior and inferior borders.
7. Superior articular process [Figure 1]
   - Height of superior articular process (HSAP): Measured from the inferior border to the superior vertex of the process
   - Width of superior articular process (WSAP): Length of the transverse diameter of the process
   - Height of inferior articular process (HIAP): From the superior border to the inferior vertex of the process
   - Width of inferior articular process (WIAP): Length of the transverse diameter of the process.

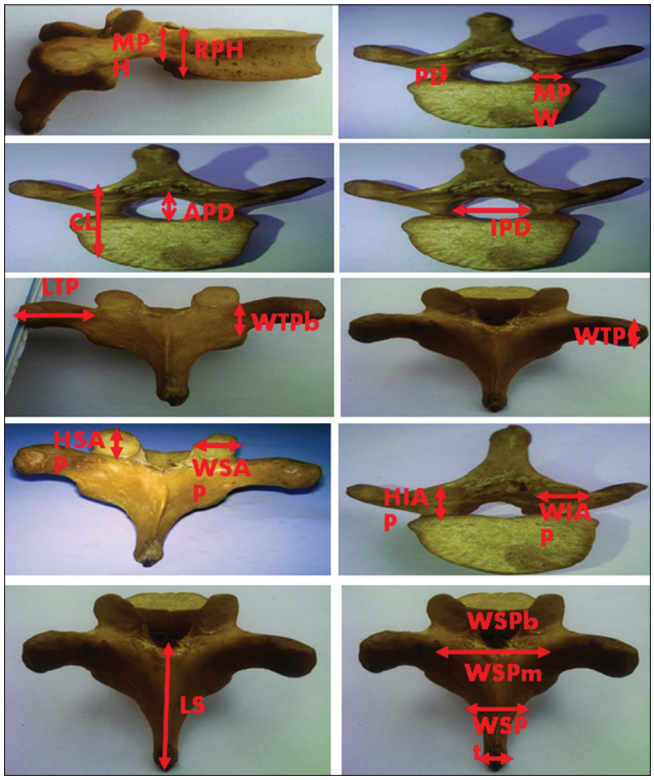

Figure 1: Captured images of the parameters measured. MPH: Mid-pedicle height, RPH: Root Pedicle height, PL: Pedicle length, MPW: Mid-pedicle width, CL: Chord length, APD: Anteroposterior distance of vertebral canal, IPD: Interpedicular distance, LTP: Length of transverse process, WTPb: Width of transverse process base, WTPt: Width of transverse process tip, HSAP: Height of superior articular process, WSAP: Width of superior articular process, HIAP: Height of inferior articular process, WIAP: Width of inferior articular process, LSP: Length of spinous process, WSPb: Width of spinous process at the base, WSPm: Width of spinous process in the middle and WSPt: Width of spinous process at the tip

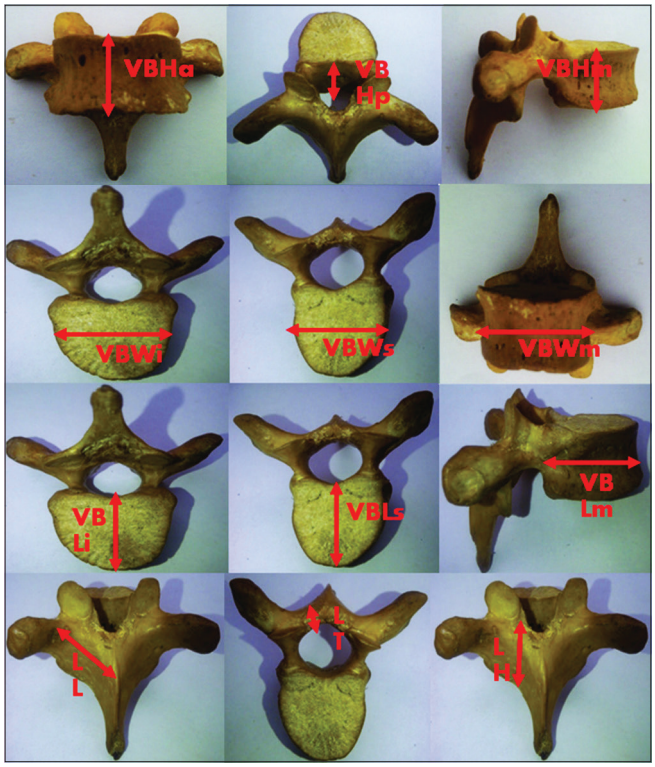

Figure 2: Captured images of the parameters measured. MPW: Mid-pedicle width, VBHa: Vertebral body height anterior, VBHp: Vertebral body height posterior, VBHm: Vertebral body height middle, VBWi: Vertebral body width inferior, VBWs: Vertebral body width superior, VBWm: Vertebral body width middle, VBLi: Vertebral body length inferior, VBLs: Vertebral body length superior, VBLm: Vertebral body length middle, LL: Lamina length, LT: Lamina thickness and LH: Lamina height

Precautions

- We ensured that all vertebrae with any form of gross abnormalities such as osteoporosis, kyphosis and scoliosis were not included
- We also ensured that the measurements were taken three times and the average was derived to ensure accuracy
- It was ensured that zero settings were applied on the digital caliper
- All measurements were taken by one person to avoid inter-observer variability.

Result and Discussion

This is the first comprehensive analysis of the morphometry of the typical thoracic vertebrae, and it has gone a long way in evincing the hitherto unstudied dimensions of the vertebrae. In the present study, the shape of the neural canal was found to be oval from T2 to T9 [Table 1]. This was in consonance with study in an Indian population.[7] In the present study, the IPD gradually decreased to T5 with a gradual increase from T6 to T9 and the least value at T9 (15.30 ± 1.48 mm). In previous studies,[18-20] similar trends were also observed, but the study[21] showed higher values at all levels and with uniformly increasing trend from T2 to T9.

The present study has the highest value of APD value at T6 level with the mean value of 14.49 ± 0.97 mm. The least mean value was observed at T3 (13.69 ± 1.48 mm). APD values were relatively stable between T2 to T9 (13.69–14.49) [Table 1]. Previous study on the Indian population[9] and on Chinese Singaporeans[22] reported similar findings with relative stability with mean values between T1 (13.82 mm) and T12 (15.87 mm) and T1 (11.6 mm) to T12 (12.4 mm), respectively.

MPH [Table 2] had a gradual increase from T2 to T9 with the least value at T2 (11.08 ± 1.73 mm) and highest at T9 (12.76 ± 1.31 mm). The same trend was observed in the studies.[9,17,22] RPH [Table 2] had its highest value at T9 (13.49 ± 1.26 mm) and least at T6 (12.01 ± 1.26 mm). RPH values decreased gradually from T2 to T6 with a gradual increase from T7 to T9. This is in consonance with the study.[9]

The PL values [Table 3] increased gradually from T2 to T9 with its greatest value at T8 (12.72 ± 2.33 mm) and smallest at T3 (10.16 ± 2.54 mm) which was in consonance with the study,[23] but minimum value was at the level of T6 with the mean of 6.48 mm.[9] The CL values [Table 3]

Table 1: Showing Descriptive Statistics for Canal Dimensions

Vertebrae level		*n*	Minimum	Maximum	Mean±S.D
T2	APD	26	12.36	16.48	14.24±1.07
	IPD	26	13.44	21.25	17.01±2.02
T3	APD	26	11.05	17.63	13.69±1.48
	IPD	26	13.74	18.39	15.96±1.32
T4	APD	26	11.80	15.69	13.97±1.26
	IPD	26	13.23	20.78	15.48±1.55
T5	APD	26	12.26	15.65	14.12±1.03
	IPD	26	12.64	20.75	15.94±1.44
T6	APD	26	12.64	16.41	14.49±0.97
	IPD	26	12.64	21.73	16.19±1.97
T7	APD	26	12.24	17.11	14.48±1.25
	IPD	26	12.90	18.58	15.73±1.37
T8	APD	26	10.17	18.11	14.32±1.68
	IPD	26	12.78	19.56	15.53±1.89
T9	APD	26	12.18	16.66	13.98±1.21
	IPD	26	12.79	17.88	15.30±1.48

Table 2: Descriptive Statistics-Pedicle Dimensions (mm)

Vertebrae level		*n*	Minimum	Maximum	Mean±S.D
T2	MPH	26	8.34	14.39	11.08±1.73
	RPH	26	10.10	15.01	12.41±1.48
T3	MPH	26	8.49	14.88	12.07±1.62
	RPH	26	10.18	15.13	12.25±1.31
T4	MPH	26	6.23	14.93	11.15±1.94
	RPH	26	8.68	15.50	12.18±1.52
T5	MPH	26	6.43	14.20	11.32±1.81
	RPH	26	9.79	14.27	12.12±1.23
T6	MPH	26	8.77	13.13	11.21±1.26
	RPH	26	9.89	15.01	12.01±1.26
T7	MPH	26	8.43	14.37	11.41±1.55
	RPH	26	8.72	15.64	12.26±1.60
T8	MPH	26	8.61	13.51	11.52±1.22
	RPH	26	10.09	15.54	12.46±1.17
T9	MPH	26	10.46	15.82	12.76±1.31
	RPH	26	11.12	15.66	13.49±1.26

Table 3: Descriptive Statistics- second set of Pedicle Dimensions (mm)

Vertebrae level		*n*	Minimum	Maximum	Mean±S.D
T2	PL	26	6.50	20.00	10.58±2.62
	CL	26	21.83	37.80	30.73±3.23
T3	PL	26	6.12	20.00	10.16±2.54
	CL	26	26.01	37.85	31.56±2.91
T4	PL	26	6.65	20.00	11.13±2.37
	CL	26	25.22	41.09	32.65±3.42
T5	PL	26	6.93	19.00	11.21±2.48
	CL	26	23.17	37.73	32.97±3.29
T6	PL	26	8.44	15.31	11.95±1.87
	CL	26	27.48	38.51	34.49±3.24
T7	PL	26	8.21	16.76	11.72±2.21
	CL	26	15.07	41.77	34.99±5.35
T8	PL	26	8.15	16.67	12.72±2.33
	CL	26	17.15	43.10	35.94±5.05
T9	PL	26	8.51	15.94	12.17±2.03
	CL	26	29.37	42.62	37.40±3.83

Table 4: Descriptive Statistics- Third set of Pedicle Dimensions (mm)

Vertebrae level		*n*	Minimum	Maximum	Mean±S.D
T2	MPW	26	3.20	11.32	6.59±2.0
T3	MPW	26	2.84	11.08	5.85±1.85
T4	MPW	26	2.61	11.93	5.78±2.01
T5	MPW	26	3.23	13.45	5.94±2.20
T6	MPW	26	3.33	14.64	6.06±2.14
T7	MPW	26	3.01	9.00	5.79±1.53
T8	MPW	26	2.88	8.68	5.43±1.32
T9	MPW	26	3.77	8.52	5.98±1.33

gradually increased from T2 to T9 to reach its maximum value at T9. This is consonance with the works in Dakshina Kannada population on Indians.[9,23,24] This study showed higher mean values of T9 at 37.40 mm and T2 at 30.73 mm than 24.60 mm–34.26 mm.[9]

The MPW [Table 4] had the minimum value at T8 (5.98 ± 1.33 mm) and maximum at T2 (6.59 ± 2.0 mm). It gradually decreased from T2 to T8 and increased at T9 [Table 4] which was in consonance with studies of some authors.[2,25,26] The oval shape of the pedicle cross section can be explained by comparison of pedicle width and PH since the PH is more than pedicle width at all levels.

In the vertebral body dimensions, the VBHa [Table 5] gradually increased from T2 to a maximum value at T9 (18.83 ± 1.54 mm). The present study was in consonance with the study of some authors.[9] The VBHm [Table 5] had a gradual increase from T2 to its maximum at T9 (19.23 ± 1.56 mm) with a minimum at T2 (16.95 ± 1.48 mm). To the best of our knowledge, no study has been conducted on the VBH at its middle plain (VBHm). The VBHp [Table 5] value was at its minimum at T2 (17.59 ± 1.43 mm) and maximum at T9 (20.46 ± 3.08 mm). A gradual increase was noticed from T2 to T9 in the present study. This result was supported by some authors.[9,22] The VBHa was found to be less as compared to the VBHp at all levels. This observation explains for the normal physiological kyphosis present in the thoracic region. Vertebral height was higher in the present study than that reported by some authors.[9,22] This could be a direct pointer to racial and environmental differences.

The VBWi gradually decreased from T2 to T4 [Table 6], and it started increasing from T4 to T9 with the maximum at T9 (30.44 ± 3.60 mm) and minimum at T4 (27.33 ± 2.90 mm). A similar trend was observed.[22] The VBWs value [Table 6] was at its minimum at T2 (26.00 ± 2.11 mm) and maximum at

Table 5: Descriptive Statistics-Vertebral Body Dimensions (mm)

Vertebrae level		*n*	Minimum	Maximum	Mean±S.D
T2	VBHa	26	13.57	20.14	16.93±1.57
	VBHm	26	14.80	20.31	16.95±1.48
	VBHp	26	14.99	20.55	17.59±1.43
T3	VBHa	26	13.95	20.00	17.27±1.42
	VBHm	26	14.37	20.58	17.60±1.74
	VBHp	26	14.86	25.58	18.54±1.99
T4	VBHa	26	14.02	19.69	17.07±1.59
	VBHm	26	15.20	20.46	17.79±1.55
	VBHp	26	15.45	20.35	18.25±1.39
T5	VBHa	26	14.03	20.49	17.55±1.65
	VBHm	26	14.98	21.02	18.23±1.54
	VBHp	26	15.03	21.88	18.62±1.78
T6	VBHa	26	14.00	20.99	17.68±1.74
	VBHm	26	14.38	22.07	18.25±1.73
	VBHp	26	15.12	22.30	18.79±1.75
T7	VBHa	26	14.65	22.22	18.34±1.78
	VBHm	26	15.70	24.15	18.86±1.80
	VBHp	26	16.62	23.93	19.30±1.76
T8	VBHa	26	14.01	22.43	18.19±2.06
	VBHm	26	15.37	22.17	18.77±1.79
	VBHp	26	16.30	23.36	19.51±1.81
T9	VBHa	26	14.98	20.83	18.83±1.54
	VBHm	26	15.37	21.87	19.23±1.56
	VBHp	26	16.43	33.48	20.46±3.08

Table 6: Descriptive Statistics-Vertebral Body Width (mm)

Vertebrae Level		*n*	Minimum	Maximum	Mean±S.D
T2	VBWi	26	21.95	34.69	28.56±3.22
	VBWs	26	23.18	30.91	26.00±2.11
	VBWm	26	21.79	30.66	25.95±2.15
T3	VBWi	26	23.99	32.69	28.31±2.24
	VBWs	26	22.33	31.47	26.44±2.10
	VBWm	26	21.02	28.85	25.66±1.78
T4	VBWi	26	22.03	33.18	27.33±2.90
	VBWs	26	21.33	31.17	26.18±2.27
	VBWm	26	20.17	29.80	25.73±2.31
T5	VBWi	26	19.36	35.54	28.09±3.57
	VBWs	26	21.36	32.94	26.61±2.71
	VBWm	26	21.03	31.32	25.37±2.37
T6	VBWi	26	24.51	31.73	28.59±1.99
	VBWs	26	22.55	29.52	26.67±1.86
	VBWm	26	21.94	31.80	26.92±2.27
T7	VBWi	26	22.07	37.56	28.89±3.51
	VBWs	26	21.30	34.47	27.41±3.00
	VBWm	26	20.52	33.80	26.26±2.74
T8	VBWi	26	24.76	33.35	28.89±2.70
	VBWs	26	23.53	32.09	27.47±2.39
	VBWm	26	22.67	31.47	26.88±2.59
T9	VBWi	26	25.15	37.92	30.44±3.60
	VBWs	26	22.67	34.39	28.97±3.30
	VBWm	26	24.00	34.22	28.22±2.85

T9 (28.97 ± 3.30 mm). The VBWs had a gradual increase from T2 to T9 which is in consonance with the study.[22] The VBWm [Table 6] was in consonance with the gradual increase from T2 to T9 in the study;[7] however, the values were lower (VBWm-T2: 25.37 mm-T9:28.22 mm) as compared to T2: 28.8 mm-T9:30.66 mm. Furthermore, this could be a direct pointer to racial and environmental influence on the structural dimensions of human vertebrae.

The VBLi value [Table 7] was at its minimum at T2 (18.93 ± 2.52 mm). The VBLi had a gradual increase from T2 and reached its maximum at T9 (24.60 ± 3.27 mm). The VBLs [Table 7] gradually increased from T2 to a maximum value at T9 (23.90 ± 3.44 mm). The minimum VBLs were observed at T2 (18.09 ± 2.47 mm). The VBLm [Table 7] had a minimum value at T2 vertebrae with the mean of (18.38 ± 2.44 mm). There was a gradual increase from T2 to the maximum at T9 (23.76 ± 3.57 mm). Having extensively searched through numerous engines, this is the first study to report these categories of these dimensions of vertebrae body length-VBLi, VBLs, and VBLm.

In the dimensions of the transverse process, the LTP had a minimum value at T3 (26.81 ± 2.80 mm) and maximum at T5 (28.42 ± 2.63 mm). There were relatively stable values from T2 to T9 [Table 8]. The present study was in contrast with study,[9] whose transverse process length (LTP) increased from T1 (14.12 mm-whole series mean), reached a maximum value at T6 with mean of 19.4 mm and decreased gradually to reach minimum value at T12 with the mean of 8.93 mm for the whole series. The WTPb [Table 8] gradually increased from T2 to a maximum value at T9 (17.32 ± 1.98 mm) with the minimum at T2 (15.13 ± 1.99 mm). This study was in contrast with the study of some authors.[9] They stated that WTPb was relatively stable between T1 and T12. The maximum value was found at T8 level with the mean of 11.7 mm for the whole series and the minimum value was at T12 with the mean of 10.13 mm for whole series.[9] This implies that the maximum value seen in the T9 of this study is far larger than that seen in the T8 of the study.[9] The WTPm values [Table 9] increased gradually from T2 to T9 with a maximum value at T9 (12.25 ± 1.84 mm) and the minimum at T3 (10.80 ± 1.44 mm). No study had previously been conducted on the WTPm. The minimum value of WTPt was at T9 (12.15 ± 2.01 mm). There were relatively stable values from T2 to T9 [Table 9] with the maximum at T6 (12.38 ± 1.59 mm). No study has been conducted on the WTPt. These novel dimensions that are being reported will definitely enhance the design of near perfect prosthetic and orthotic materials needed in the repair or maintenance of the structural integrity of the thoracic segment of the human spine.

Table 7: Descriptive Statistics-Vertebral body length (mm)

Vertebrae level		*n*	Minimum	Maximum	Mean±S.D
T2	VBLi	26	13.32	23.59	18.93±2.52
	VBLs	26	13.22	22.98	18.09±2.47
	VBLm	26	13.45	23.30	18.38±2.44
T3	VBLi	26	15.54	24.46	19.87±2.50
	VBLs	26	14.70	24.28	19.17±2.54
	VBLm	26	15.03	27.94	19.39±2.82
T4	VBLi	26	15.47	25.50	20.91±2.83
	VBLs	26	14.15	25.42	20.12±2.82
	VBLm	26	14.15	25.34	20.29±2.74
T5	VBLi	26	14.53	27.31	21.12±2.99
	VBLs	26	13.72	24.68	20.09±2.77
	VBLm	26	14.30	25.20	20.21±2.68
T6	VBLi	26	15.14	26.41	22.07±3.11
	VBLs	26	14.41	24.97	21.12±3.00
	VBLm	26	14.49	27.92	21.40±3.17
T7	VBLi	26	17.30	28.44	22.83±3.02
	VBLs	26	16.70	26.76	22.03±2.87
	VBLm	26	16.19	26.92	22.05±2.86
T8	VBLi	26	16.53	28.41	23.05±2.85
	VBLs	26	16.48	27.22	22.42±2.92
	VBLm	26	16.71	27.14	22.55±2.81
T9	VBLi	26	18.64	29.49	24.60±3.27
	VBLs	26	16.96	28.74	23.90±3.44
	VBLm	26	16.92	28.09	23.76±3.57

Table 9. Descriptive Statistics- Second set of Transverse Process Dimensions (mm)

Vertebrae level		*n*	Minimum	Maximum	Mean±S.D
T2	WTPm	26	8.45	16.60	11.45±1.67
	WTPt	26	9.07	16.67	12.53±1.75
T3	WTPm	26	7.54	13.31	10.80±1.44
	WTPt	26	10.99	15.27	12.80±1.30
T4	WTPm	26	8.01	14.78	11.19±1.40
	WTPt	26	8.96	16.71	12.44±1.90
T5	WTPm	26	7.90	15.30	11.57±1.71
	WTPt	26	10.43	18.91	12.97±1.80
T6	WTPm	26	8.98	14.97	11.63±1.65
	WTPt	26	9.30	14.79	12.38±1.59
T7	*WTPm	26	9.27	14.80	11.78±1.46
	WTPt	26	8.73	19.31	13.00±2.44
T8	WTPm	26	9.72	14.89	11.88±1.47
	WTPt	26	9.20	17.35	12.74±2.10
T9	WTPm	26	9.28	16.93	12.25±1.84
	WTPt	26	7.67	15.85	12.15±2.01

The spinous process dimensions measured include LSP and WSPb, and WSPm and WSPt. The LS*P* value [Table 10] was at its minimum at T2 (35.65 ± 5.00 mm). The LSP had a gradual increase from T2 to T9 with the maximum at T7 (39.50 ± 4.77 mm) which is in consonance with study.[23] The WSPb [Table 10] had a gradual increase and reached its maximum at T9 (34.48 ± 2.80 mm)

Table 8: Descriptive Statistics- first set of Transverse Process Dimensions (mm)

Vertebrae level		*n*	Minimum	Maximum	Mean±S.D
T2	LTP	26	22.68	33.23	27.72±2.46
	WTPb	26	11.62	20.27	15.13±1.99
T3	LTP	26	21.21	31.33	26.81±2.80
	WTPb	26	11.65	20.19	15.45±2.26
T4	LTP	26	22.13	32.20	27.10±2.54
	WTPb	26	12.01	20.77	15.81±2.15
T5	LTP	26	23.39	33.46	28.42±2.63
	WTPb	26	12.16	21.78	16.39±2.31
T6	LTP	26	17.26	31.52	27.41±2.95
	WTPb	26	12.80	25.56	16.50±2.58
T7	LTP	26	22.16	34.16	28.04±3.20
	WTPb	26	13.75	20.94	17.14±2.25
T8	LTP	26	22.41	32.40	28.06±2.37
	WTPb	26	13.85	23.08	17.20±2.41
T9	LTP	26	22.54	31.47	27.58±2.36
	WTPb	26	14.31	20.92	17.32±1.98

Table 10: Descriptive Statistics-Spinous Process Dimensions (mm)

Vertebrae level		*n*	Minimum	Maximum	Mean±S.D
T2	LSP	26	25.60	47.88	35.65±5.00
	WSPb	26	18.26	44.57	33.24±5.30
T3	LSP	26	23.67	46.50	36.59±5.41
	WSPb	26	24.22	41.89	32.11±3.54
T4	LSP	26	22.02	46.63	37.28±5.24
	WSPb	26	24.14	41.66	31.85±3.34
T5	LSP	26	28.78	47.30	38.52±4.96
	WSPb	26	26.20	40.77	32.67±3.53
T6	LSP	26	29.30	47.47	36.97±4.69
	WSPb	26	27.18	43.59	33.67±3.53
T7	LSP	26	32.17	48.42	39.50±4.77
	WSPb	26	22.73	42.17	33.13±3.54
T8	LSP	26	31.20	49.28	39.04±4.97
	WSPb	26	28.94	38.31	33.30±2.50
T9	LSP	26	28.33	45.76	37.37±4.94
	WSPb	26	29.35	39.31	34.48±2.80

with a minimum value at T4 (31.85 ± 3.34 mm). The maximum value of WSPm [Table 11] was at T2 vertebrae with the mean of (14.74 ± 2.89 mm). There was a gradual decrease from T2 to T9 with the minimum at T8 (13.45 ± 2.39 mm). The WSPt value [Table 11] was at its minimum at T4 (4.42 ± 0.86 mm). The WSPt had relatively stable values from T3 to T9 with the maximum at T2 (5.05 ± 1.36 mm). Apart from LSP, no previous study has been conducted on the WSPt, WSPm, and WSPb. This further emphasizes the novelty of our findings.

The Lamina dimensions measured were LL, LH, and LT. The LL had a relatively stable value [Table 12] from T2 to T9 with a maximum value

Table 11: Descriptive Statistics for second set of Spinous Process Dimensions (mm)

Vertebrae Level		*n*	Minimum	Maximum	Mean±S.D
T2	WSPm	26	8.00	22.76	14.74±2.89
	WSPt	26	3.21	8.61	5.05±1.36
T3	WSPm	26	8.42	17.41	13.69±2.21
	WSPt	26	2.88	8.30	4.42±1.13
T4	WSPm	26	8.61	18.66	14.17±2.17
	WSPt	26	2.86	6.73	4.42±0.86
T5	WSPm	26	9.23	16.82	13.60±2.20
	WSPt	26	3.22	6.58	4.48±1.0
T6	WSPm	26	10.46	20.04	13.87±2.09
	WSPt	26	3.17	10.27	4.94±1.50
T7	WSPm	26	10.97	19.72	14.07±2.06
	WSPt	26	2.80	7.17	4.60±1.11
T8	WSPm	26	8.40	18.30	13.45±2.39
	WSPt	26	2.66	8.21	4.73±1.03
T9	WSPm	26	5.48	23.76	13.46±3.29
	WSPt	26	3.39	12.87	4.97±1.88

Table 12: Descriptive Statistics- Lamina Dimensions (mm)

Vertebrae level		*n*	Minimum	Maximum	Mean±S.D
T2	LL	26	16.29	26.22	20.82±2.58
	LT	26	4.92	8.89	6.60±1.16
	LH	26	13.61	23.41	16.86±2.32
T3	LL	26	17.63	24.03	20.17±1.85
	LT	26	4.39	8.49	6.89±1.08
	LH	26	13.56	22.28	17.95±2.13
T4	LL	26	14.87	27.20	19.04±2.69
	LT	26	4.42	8.80	6.69±1.28
	LH	26	9.99	24.07	17.55±2.77
T5	LL	26	15.68	23.74	19.67±2.01
	LT	26	5.00	9.70	7.23±1.17
	LH	26	13.14	22.95	18.46±2.42
T6	LL	26	15.13	31.79	20.01±3.50
	LT	26	4.89	9.04	6.68±1.22
	LH	26	15.16	25.38	18.37±2.21
T7	LL	26	16.17	24.32	19.89±2.75
	LT	26	4.72	9.55	7.09±1.35
	LH	26	14.46	24.07	18.91±2.22
T8	LL	26	15.30	24.17	19.73±2.10
	LT	26	4.65	9.81	6.87±1.17
	LH	26	15.42	25.17	20.00±2.60
T9	LL	26	17.35	24.59	20.28±1.79
	LT	26	4.99	11.59	7.30±1.24
	LH	26	14.74	25.78	19.49±2.48

Table 13: Descriptive Statistics-Superior Articular Processes Dimensions (mm)

Vertebrae level		*n*	Minimum	Maximum	Mean±S.D
T2	HSAP	26	10.21	17.78	13.81±1.52
	WSAP	26	7.25	18.00	11.18±2.61
T3	HSAP	26	9.75	16.91	13.70±1.57
	WSAP	26	7.86	15.24	10.16±1.79
T4	HSAP	26	9.00	16.36	13.64±1.81
	WSAP	26	7.23	14.89	10.00±1.89
T5	HSAP	26	11.24	17.12	14.01±1.61
	WSAP	26	6.76	14.43	10.35±2.01
T6	HSAP	26	11.28	17.38	14.42±1.64
	WSAP	26	7.54	13.50	9.99±1.48
T7	HSAP	26	11.22	18.73	14.80±1.92
	WSAP	26	7.63	13.86	10.33±1.67
T8	HSAP	26	10.38	17.89	14.66±1.60
	WSAP	26	7.74	16.25	10.45±1.69
T9	HSAP	26	10.46	19.04	14.71±1.82
	WSAP	26	7.78	12.29	9.88±1.21

Table 14. Descriptive Statistics-Inferior Articular Processes Dimensions (mm)

Vertebrae level		*n*	Minimum	Maximum	Mean±S.D
T2	HIAP	26	9.24	14.98	12.18±1.58
	WIAP	26	8.35	13.51	10.84±1.43
T3	HIAP	26	8.87	14.10	12.17±1.18
	WIAP	26	8.43	12.33	10.38±1.00
T4	HIAP	26	8.62	14.47	11.61±1.36
	WIAP	26	7.07	13.56	10.22±1.44
T5	HIAP	26	10.04	14.00	12.28±1.25
	WIAP	26	8.10	12.87	10.70±1.34
T6	HIAP	26	9.99	15.37	12.53±1.46
	WIAP	26	8.27	12.35	10.61±1.17
T7	HIAP	26	7.95	14.45	12.42±1.59
	WIAP	26	8.32	16.87	10.95±1.66
T8	HIAP	26	9.29	16.16	12.81±1.46
	WIAP	26	9.20	13.31	10.97±1.16
T9	HIAP	26	10.14	14.52	12.47±1.01
	WIAP	26	7.66	14.00	11.11±1.49

at T1 (20.82 ± 2.58 mm) and the minimum at T4 (19.04 ± 2.69 mm). The LT values [Table 12] were relatively stable from T2 to T9 with a maximum value at T9 level with the mean of (7.30 ± 1.24 mm) and the minimum at T2 (6.60 ± 1.16 mm). The LH values [Table 12] increased from T2 to T9 with the maximum at T8 (20.00 ± 2.60 mm) and the minimum at T2 (16.86 ± 2.32 mm). No previous study has reported values for LL, LT, and LH. Therefore, prosthetic designs of the laminae of the thoracic vertebrae can be done to further enhance aptness in the functionality of the interventional procedures involving the spine.

In the dimensions of superior articular processes, HSAP and WSAP were recorded. The maximum value of HSAP was at T7 (14.80 ± 1.92 mm). There was a gradual increase from T2 to T7 [Table 13] with the minimum value at T4 (13.64 ± 1.81 mm). The WSA*P* values [Table 13] were relatively stable from T2 to T9 with a maximum value at T2 (11.18 ± 2.61 mm) and the minimum at T9 (9.88 ± 1.21 mm). No study has been conducted on the HSAP, WSAP. The inferior articular processes dimensions measured were HIAP and WIAP. The HIAP values were

relatively stable values from T2 to T9 [Table 14] with the minimum at T4 (11.61 ± 1.36 mm) and the maximum at T8 (12.81 ± 1.46 mm). There was a gradual increase from T2 to T9 [Table 14] with the minimum value of WIAP at T4 (10.22 ± 1.44 mm) and the maximum at T9 (11.11 ± 1.49 mm). This is the first study to report values of HIAP and WIAP. The novelty of these dimensions of the articular facets will help in the design of perfectly fit wires and hooks that will aid further stability and spine fixation procedures.

From the above, some of our findings that are in contrast with those of other studies may be as a result of different biomechanical inclinations that are cultural and racial. These diverse biomechanical or postural inclinations of the component parts of the spine associated with race, ethnicity, and culture would have led to the observed differences in the dimensions of the component parts of the thoracic vertebrae. Furthermore, the stature and other anthropometric variables of the study populations may also contribute to the outcome of these differing vertebrae dimensions. We, therefore, recommend that special consideration be given to the morphometric data obtained in the present study, during the modification of spinal implants (screw/hooks/cages) and modeling of typical thoracic vertebrae.

Conclusion

Most of the changes in the parameters from T2 to T9 can be as a result of racially induced localized musculoskeletal disposition and biomechanical stresses. The results from this study will help to understand the characteristic features of typical thoracic vertebrae, enhance preclinical evaluation of vertebral implants and other prosthetic materials and management of spine pathology in the Nigerian population. Data collected in the present study provided baseline normative values of the vertebral body, vertebral foramen, pedicle, lamina, spinous and transverse processes, superior and inferior articular processes suitable for the construction of models for learning and surgical replacement procedures.

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Conflicts of interest

There are no conflicts of interest.

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