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The frequency and presentation of upper thoracic spinous process deviations, their relationship to articular morphology, and the potential influence on static palpation techniques

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ABSTRACT

Background: Static palpation of vertebral spinous process deviations from the midline are often utilized by manual therapists as a means to determine area for treatment of manipulable lesions. Previous research has discussed the diagnostic validity of this technique, but no correlation to vertebral morphology has been presented.
Aim: To evaluate the frequency and presentation of vertebral spinous process deviations and their relationship with articular morphology, and the impact this may have in terms of static palpation techniques in the upper thoracic spine.
Setting: This study was conducted on human T1-T6 vertebrae.
Method: A skeletal sample consisting of 58 humans T1-T6 vertebrae were photographed and linear and angular measurements taken utilizing ImageJ software and non-metric visual observations.
Results: Spinous process deviations in the entire sample group (n = 348) were found to occur in a frequency ranging from 19% (n = 11) at T1 to 41.4% (n = 24) at T3. However, when evaluated in terms of frequency within an individual's T1-T6, 83.3% (n = 25) of males and 67.86% (n = 19) of females demonstrated this feature, with an overall incidence of 77.59% (n = 45). Age of individuals did not show an increase in frequency, and no clear pattern could be identified regarding metric measurements and its presence.
Conclusion: Spinous process deviations in the upper thoracic spine are most probably the result of random normal variations between individuals and are more frequent in males. Static palpation without pain criteria is not a reliable diagnostic technique to determine areas needing manual treatment, as these may be considered normal osseous anatomical variations.

1. Introduction

The thoracic spine is considered a common site for normal skeletal and joint

Morphological variations (Edmonston and Singer, 1997) and in a clinical setting, static palpation of the human spinous processes is utilized in manual therapy as a means of assessment and a determination of where treatment interventions for manipulable lesions should be focused (Walker and Buchbinder, 1997; Holmgren and Waling, 2008; Gross et al., 1996). Static palpation is defined by Bergmann and Peterson (2010) as the palpation of bony landmarks incorporating a manual scanning assessment of contour, tenderness, and alignment of the spinous processes, transverse processes, rib angles, interspinous space and intercostal space. The alignment of spinous processes as a component of this technique may be influenced by vertebral morphometry and variations.

When considering spinous processes, they may be considered as enthesis points, and may be subjected to various forces. Bone remodeling has been shown to create changes which are mechanically appropriate according to loading, known as Wolff's law, which states that natural healthy bone will adapt and change to the stress that it is subjected to and therefore the primary mechanism for bone adaptation is

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mechanical loading (Wolff, 1870; Enlow, 1962). This mechanical loading may also stimulate periosteal growth (Pearson and Lieberman, 2004). Sharpey's fibers are responsible for anchoring of muscles to bone by passing through the periosteum (Benjamin et al., 2002). When muscles' entheses are subjected to increased force of contracting muscles, blood flow to the periosteum increases, which can stimulate bone growth and increase the size of attachment sites to strengthen them (Montgomery et al., 2005).

Spinous process deviation is a morphological feature that may be the result of rotation of the entire vertebra or developmental asymmetry of the neural arch (Mellado et al., 2011). Ravichandrin (1983) proposed that spinous process deviation may be seen in patients with lumbar spine disc protrusion. However, Tang et al. (2015) found that spinous process deviation of the lumbosacral segments is common, but found no correlation to disc degeneration. In the cervical spine, MacPherson and Campbell (1991) evaluated C2 spinous process deviation (or asymmetrical prominence) in relation to the patient presenting with a migraine type headache and found the control and symptomatic groups had similar incidences, concluding that any association was incidental.

Lewit (1957) found that 80% of young adults presented with spinous process deviation and proposed that the deviations were a result of asymmetrical muscle pull, if one considers that they are muscle insertion points and the bone has plastic properties to load (Wolff, 1870). Four possible changes were noted.

a. Simple deviation as an anomaly in an individual (especially if occurring at multiple levels in different directions),
b. Deviation of the center of the spinous arch (i.e., root of the spinous process),
c. Deviation of the spinous process with associated or combined signs of vertebral rotation (altered pedicle),
d. Change in axis of spinous process (i.e., deviation of several or all spinous processes from a certain point).

Van Schaik et al. (1989) describe spinous process deviation as the result of one or more of several possible causes. These include rotation of the entire vertebrae (as in scoliosis), developmental asymmetry of the neural arch, or isolated deviation. Van Schaik et al. (1989) concluded that the oval shadow seen on anterior-posterior radiographs is the tip of the spinous process (not the base) and was therefore not a reliable method of differentiating the three types. Mellado et al. (2011) utilized multidetector computed tomography (MDCT) to identify variations in spinous process presentation and demonstrate isolated developmental spinous process deviation radiographically and on MDCT.

From a historic context in chiropractic, the subluxation and the joint being out of place has been purported since the inception of the profession. Technique systems continue to teach and propose palpation techniques to determine alignment of spinous processes as a means of determining where manipulation should be applied. Haneline and Young (2009) presented a literature synthesis of intra and inter examiner reliability of static spinal palpation techniques and concluded that when comparing tenderness, landmarks and position or alignment of bone structures, no technique was superior, although the use of pain showed more validity. Stochkendahl et al. (2006) found compelling evidence that the interobserver reproducibility of osseous and soft tissue pain was clinically acceptable and that intra examiner reproducibility of soft tissue pain is clinically acceptable. Beynon et al. (2018) found moderate reliability if evaluating stiffness of the thoracic spine with tenderness.

While studies have focused on palpation and the inclusion of tenderness for reliability, no previous studies have commented on the prevalence or presentation of spinous process deviations as an osseous variation, and the influence these may have on the utilization of static palpation techniques in manual therapies. Therefore, this current study investigates the frequency and presentation of spinous process deviations in the T1-T6 region, potential factors that may be implicated in their development as well as the implications of these as an anatomical variation within the context of static palpation.

2. Methods

2.1. Sample

This study utilized the human skeletal sample group from a broader study comparing extant hominids and fossil hominins upper thoracic vertebrae (T1-T6) morphometric features. The sample consisted of randomly selected upper thoracic vertebrae (T1-T6) from the collection repositories of the Raymond A. Dart Collection of Human Skeletons, School of Anatomical Sciences, University of Witwatersrand, and the Department of Human Anatomy and Physiology, Human osteology laboratory, University of Johannesburg, and had a representation of 58 individual series of vertebrae, with 30 male and 28 female. An ethics waiver was approved by School of Anatomical Sciences, University of Witwatersrand (W-CBP-220504-01) and the Faculty of Health Sciences, Research Ethics Committee, University of Johannesburg (REC-01-14-2020).

2.2. Data collection procedure

For the purposes of the current study, each vertebra was required to be photographed from a lateral, inferior and superior views. The following specified methods were applied to all specimens.

2.2.1. Photographic methodology

Each specimen was photographed utilizing the same parameters to ensure consistency of images and measurements.

2.2.2. Camera settings

A Nikon D3200 digital single reflex camera was used with a 55 mm focal length, shutter speed of 1/100s and f stop 5. The camera was set on a tripod over the light box, with a spirit level used to ensure the camera was horizontal for all images. The camera was not moved for the image sequences; only the foam block was adjusted as required.

2.2.3. Light box and foam block system

To accommodate the various bony processes emanating from the vertebra, and allow for reproducible images, each specimen was required to be placed perpendicular to the camera lens and a custom-made foam block system was therefore created and utilized (Fig. 1).

The foam block had incisions made to accommodate the transverse processes or articular processes of the vertebrae and allowed for true lateral images to be obtained. The same incision was utilized for inferior



Fig. 1. Foam block system utilized to photograph specimens. a: information tag; b: incision to accommodate articular/transverse process; c: scale bar; d: cutout to accommodate spinous process; e: spirit level.

views, where the superior articular processes were placed in the incision. This allowed for a method of stabilizing the specimen in a reproducible manner, with minimal pressure to avoid any damage to specimens utilized.

Similarly, for the superior views a cutout in the foam was made to accommodate the spinous process (and angle), allowing the vertebral body to rest supported on the foam itself.

A scale bar was included for all images, as was an information tag that included date, image, specimen, sex, and specimen number.

A custom fashioned light box with LED lighting that surrounded each specimen was utilized to ensure uniformity of light and avoid shadowing that could obscure or alter morphology and measurements. This system was designed to be collapsible and portable to allow for reproduction of the photographic techniques at the various locations required. The setup of the light box and camera are depicted in Fig. 2.

2.2.4. Specific image description

2.2.4.1. Image 1 and 2 (lateral view). Each vertebral specimen had a left and right lateral image taken. To place the vertebrae in the foam block and ensure no damage would occur to the specimen, the incision was opened by hand, and the transverse process gently inserted into the incision and the foam released to support the vertebra. While observing the image through the camera view finder, the vertebra was adjusted until the intervertebral foramen of the left and right sides were visualized equally. This ensured a true lateral view of the vertebrae, perpendicular to the camera lens and sensor. The focal point was on the proximal part of the inferior articular process. Fig. 3 is an example of a left lateral view image of T2.



Fig. 2. Example of light box and camera utilized, illustrating photography of specimens.

2.2.4.2. Image 3 (inferior view). Each vertebral specimen had an inferior view image taken. The superior articular processes were inserted into the opened incision in the foam block and then released to support the vertebra. A spirit level was placed on the inferior surface of the vertebral body and the specimen adjusted until horizontal (and therefore aligned to the leveled camera sensor). The focal point was on the convergence point of the lamina closest to the camera. Fig. 4 is an example of an inferior view image of T2.

2.2.4.3. Image 4 (superior view). Each vertebral specimen had a superior view image taken. The spinous process was placed in the cutout of the foam block with the articular processes below the top of the foam. A spirit level was placed in the superior surface of the vertebral body, and the specimen adjusted until horizontal, and therefore aligned to the leveled camera sensor. The focal point was on the convergence point of the lamina. Fig. 5 is an example of a superior view image of T2.

2.3. Measurement methodology

ImageJ (version 1.53e, NIH, USA) was utilized to measure various



Fig. 3. Example of T2 left lateral view image.



Fig. 4. Example of T2 inferior view image.



Fig. 5. Example of T2 superior view image.

morphometric measurements as indicated below. This is an open-source image programme designed for image processing and analysis. ImageJ was found to be a valid and reliable tool when compared to goniometric analysis with an Interclass Correlation Co-efficient of 0.89 (Roush et al., 2008).

The following morphometric measurements were taken for each view.

- Superior view (Fig. 6):
  - o Central spinous process deviation (this is a component of spinous process deviation, region and direction: SPDRD)
  - o Region of spinous process deviation (this is a component of spinous process deviation, region and direction: SPDRD)
  - o Dorsoventral superior articular facet width (SAFW)
  - o Dorsoventral superior articular facet orientation (SAFO)
- Inferior view (Fig. 7):
  - o Dorsoventral inferior articular facet width (IAFW)
  - o Dorsoventral inferior articular facet orientation (IAFO)
- Lateral view (Fig. 8):
  - o Spinous process length (SPL)
  - o Craniocaudal spinous process angle (SPA)

2.3.1. *Superior view measurements definitions and methods*

Specific definitions and descriptions of morphometric measurements from the superior view image are visually represented in Fig. 6 and defined in the description to follow.

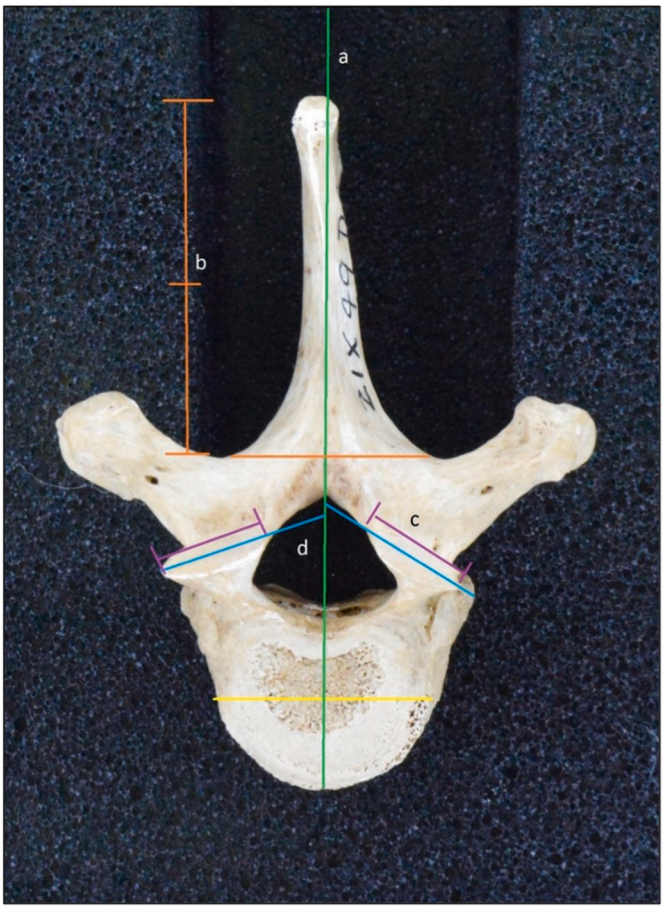


Fig. 6. Morphometric measurements taken from superior view image. a: central spinous process deviation (green line: sagittal midline of vertebra); b: region of spinous process deviation (red line); c: dorsoventral superior articular facet width (purple line); d: dorsoventral superior articular facet orientation. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

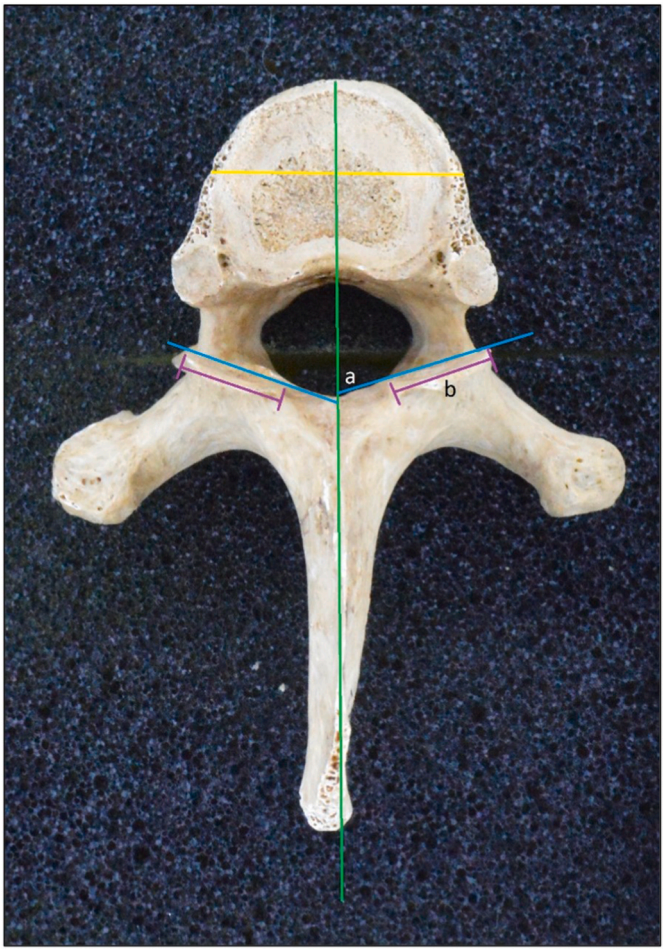


Fig. 7. Morphometric measurements from inferior view image. a: dorsoventral inferior articular facet orientation; b: dorsoventral inferior articular facet width.

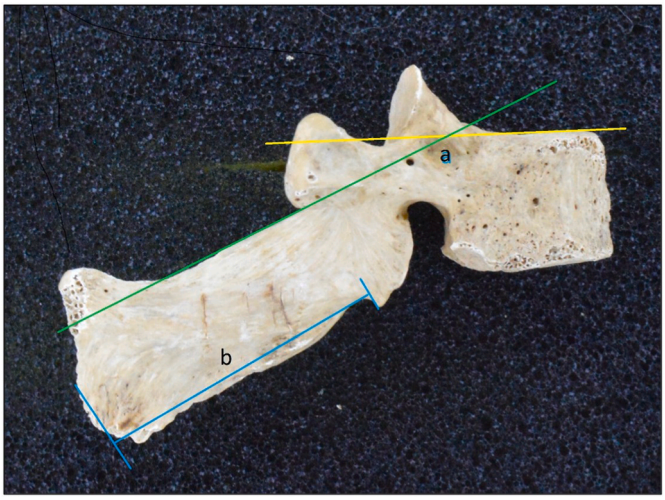


Fig. 8. Morphometric measurements from lateral view image. a: craniocaudal spinous process angle; b: spinous process length.

2.3.2. Central spinous process deviation

This measurement was a non-metric visual determination of spinous process deviation noted, relative to the sagittal midline of the vertebra (represented in Fig. 6 by the green line). This is a component of the spinous process deviation, region and direction (SPDRD) as presented in the results and discussion.

2.3.3. Region and direction of spinous process deviation

This is a non-metric visual determination of the region and direction of deviation (when these were identified). The line (based on the sagittal midline of the vertebra and represented in Fig. 6 by the red line) extended from the dorsal end/tip to the base of the spinous process (where the lamina converged). The midpoint of this line was utilized to visually determine if the occurrence of deviation was either at the proximal or distal components of the spinous process, and either right or left. This was used in conjunction with central spinous process deviation, to determine SPDRD, where a visual allocated was made of "1" for no deviation, "2" for distal left deviation, "3" for distal right deviation, "4" for proximal left deviation and "5" for proximal right deviation was determined.

2.3.4. Dorsoventral superior articular facet width (superior facet width – SFW)

This was a metric measure (in mm) of the superior articular facet dorsoventral width (represented in Fig. 6 as point "c" and the purple line). The image was calibrated in ImageJ to the measurement key and measured from the most medial to most lateral border of the articular process (Williams et al., 2018).

2.3.5. Dorsoventral superior articular facet orientation (superior facet orientation – SFO)

This measurement was defined as the ventral angle, in the transverse plane, between the lines parallel to superior articular facet surface (medial and lateral edges), and the sagittal mid plane of the vertebral body (Williams et al., 2018) and is depicted in Fig. 6 (angle "d"). The central spinous process deviation line as described, was utilized again as the reference for the articular angle. The line drawn from the dorsal surface of the superior articular facet (represented by the blue line) was extended to intersect the central spinous process deviation line (represented by the green line) with the ventral angle produced measured in degrees with ImageJ.

Measurements of the left and right angles were recorded for comparison purposes.

2.3.6. Inferior view image definitions and measurements

Specific definitions and descriptions of morphometric measurements from the inferior view image are visually represented in Fig. 7 and defined in the descriptions to follow.

2.3.7. Dorsoventral inferior articular facet width (inferior facet width – IFW)

This was a metric measure (in mm) of the inferior articular facet dorsoventral length (as indicated in Fig. 7, represented by the purple line). This image was calibrated to the key in ImageJ, and the measurement taken from the most medial to most lateral end of the articular process (Williams et al., 2018).

2.3.8. Dorsoventral inferior articular facet orientation (inferior facet orientation – IFO)

This measurement was defined as the angle, in the transverse plane, between the lines parallel to inferior articular facet surface (medial and lateral edges), and the sagittal mid plane of the vertebral body (Williams et al., 2018) and is depicted in Fig. 7. The central line spinous process deviation line (represented by the green line) was utilized again as the reference for the articular angle. The line drawn from the ventral surface of the inferior articular facet was extended to intersect the central vertebral line and the ventral angle (represented by the blue line and angle "a" in Fig. 7) produced measured in degrees with ImageJ.

Measurements of the left and right angles were recorded for comparison purposes.

2.3.9. Lateral view image definitions and measurements

Specific definitions and descriptions of morphometric measurements from the lateral view image are visually represented in Fig. 8 and defined in the descriptions to follow.

2.3.10. Craniocaudal spinous process angle (spinous process angle – SPA)

As indicated in Fig. 8, this was defined by Bräuer (1998) as the inferior angle (point "a") created between the extended line from the superior border of the spinous process (represented by green line), and the superior surface of the vertebral body (represented by the yellow line) and measured utilizing ImageJ. The superior border of the spinous process was determined by selecting a point on the origin of the spinous process superior surface and extending this to follow the superior border of the structure. The superior border of the vertebral body was determined by selecting the anterior point of the vertebral body, and the continuing the line along the body border, and then extending this to

Table 1
Mean values of morphologic measurements per vertebral level.

Measurement	N	Mean	SD	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
SPA_T1	58	142.03	8.290	1.089	139.85	144.21	119	156
SPL_T1	58	31.82	3.521	0.462	30.89	32.74	25	42
IAFW_R.T1	58	11.69	1.562	0.205	11.28	12.10	9	15
IAFW_L.T1	58	11.93	1.674	0.220	11.49	12.37	8	15
IAFO_R.T1	58	69.02	6.182	0.812	67.39	70.64	56	82
IAFO_L.T1	58	66.81	4.985	0.655	65.50	68.12	57	78
SAFW_R.T1	58	14.48	2.093	0.275	13.93	15.03	10	19
SAFW_L.T1	58	14.56	2.353	0.309	13.94	15.18	9	20
SAFO_R.T1	58	77.64	9.925	1.303	75.03	80.25	57	98
SAFO_L.T1	58	78.03	8.266	1.085	75.85	80.20	60	95
SPA_T2	58	139.45	8.722	1.145	137.15	141.74	111	155
SPL_T2	58	30.86	3.782	0.497	29.86	31.85	20	39
IAFW_R.T2	58	10.71	1.270	0.167	10.38	11.05	8	14
IAFW_L.T2	58	10.46	1.536	0.202	10.06	10.86	7	15
IAFO_R.T2	58	72.93	5.430	0.713	71.50	74.36	59	87
IAFO_L.T2	58	71.43	4.489	0.589	70.25	72.61	58	80
SAFW_R.T2	58	12.35	1.751	0.230	11.89	12.82	8	16
SAFW_L.T2	58	11.95	1.728	0.227	11.49	12.40	9	16
SAFO_R.T2	58	68.04	6.437	0.845	66.35	69.73	51	87
SAFO_L.T2	58	69.92	4.872	0.640	68.64	71.21	58	83
SPA_T3	58	136.43	8.928	1.172	134.08	138.77	114	156
SPL_T3	58	29.21	3.676	0.483	28.24	30.17	22	37
IAFW_R.T3	58	10.64	1.552	0.204	10.23	11.05	8	16
IAFW_L.T3	58	10.01	1.300	0.171	9.67	10.36	7	13
IAFO_R.T3	57	74.81	4.908	0.650	73.51	76.11	64	86
IAFO_L.T3	57	71.69	4.206	0.557	70.58	72.81	62	83
SAFW_R.T3	57	11.10	1.392	0.184	10.73	11.47	8	14
SAFW_L.T3	57	10.61	1.469	0.195	10.22	10.99	8	14
SAFO_R.T3	57	68.91	5.219	0.691	67.52	70.29	54	79
SAFO_L.T3	57	71.99	4.783	0.634	70.72	73.26	60	81
SPA_T4	58	130.07	8.833	1.160	127.75	132.40	112	149
SPL_T4	58	28.83	3.543	0.465	27.90	29.76	21	38
IAFW_R.T4	58	10.20	1.513	0.199	9.80	10.59	7	14
IAFW_L.T4	58	9.81	1.287	0.169	9.47	10.15	7	13
IAFO_R.T4	58	74.03	4.402	0.578	72.88	75.19	64	83
IAFO_L.T4	58	73.62	4.506	0.592	72.44	74.81	60	82
SAFW_R.T4	57	11.15	1.538	0.204	10.74	11.56	8	15
SAFW_L.T4	57	10.38	1.550	0.205	9.97	10.79	7	14
SAFO_R.T4	57	69.93	5.064	0.671	68.58	71.27	58	81
SAFO_L.T4	57	72.82	3.436	0.455	71.91	73.73	65	80
SPA_T5	58	125.50	8.302	1.090	123.32	127.68	108	145
SPL_T5	58	29.41	4.586	0.602	28.20	30.62	21	39
IAFW_R.T5	58	9.64	1.468	0.193	9.25	10.02	6	13
IAFW_L.T5	58	9.30	1.309	0.172	8.96	9.65	6	13
IAFO_R.T5	58	73.81	4.921	0.646	72.51	75.10	60	89
IAFO_L.T5	58	73.87	4.806	0.631	72.61	75.13	62	87
SAFW_R.T5	58	10.68	1.520	0.200	10.28	11.08	8	15
SAFW_L.T5	58	10.02	1.326	0.174	9.67	10.37	8	13
SAFO_R.T5	58	70.04	5.145	0.676	68.68	71.39	59	81
SAFO_L.T5	58	74.21	3.672	0.482	73.25	75.18	60	80
SPA_T6	58	121.71	7.769	1.020	119.67	123.76	103	139
SPL_T6	58	30.16	4.258	0.559	29.04	31.28	19	40
IAFW_R.T6	58	9.52	1.280	0.168	9.18	9.86	7	13
IAFW_L.T6	58	9.51	1.077	0.141	9.22	9.79	8	12
IAFO_R.T6	58	74.93	5.006	0.657	73.62	76.25	63	87
IAFO_L.T6	58	74.67	4.029	0.529	73.61	75.73	65	86
SAFW_R.T6	58	9.97	1.648	0.216	9.53	10.40	6	13
SAFW_L.T6	58	9.57	1.176	0.154	9.26	9.88	6	12
SAFO_R.T6	58	69.66	5.408	0.710	68.24	71.08	52	82
SAFO_L.T6	58	73.79	4.072	0.535	72.72	74.86	63	84

Key: Spinous process angle (SPA), inferior articular facet orientation (IAFO), superior articular facet orientation (SAFO) measured in degrees.
Spinous process length (SPL), inferior articular facet width (IAFW), superior articular facet width (SAFW) measured in mm.

intersect with the extended line of the spinous process.

2.3.11. Spinous process length (SPL)

This was the physical measurement of the spinous process length (in mm), from the posterior aspect of the inferior articular process to the end of the spinous process, following the inferior margin of the process (represented in Fig. 8 by the blue line). The image was calibrated to the key in ImageJ prior to measurement.

2.4. Data analysis

Descriptive statistics and frequencies were utilized for all measurements to explore the nature of the variables measured and describe the characteristics (Pallant, 2007). These included analysis and presentation of.

- Frequencies of spinous process deviation (counts and percentages) within the sample group and split by sex.
- Morphometric measurements and spinous process deviation, region and direction (SPDRD) frequencies, means, maximum/minimum, standard deviations.

3. Results

3.1. Demographic data of sample group

The overall sample of 58 individuals' T1-T6 vertebrae were assessed (total of 348 vertebrae), with 51.72% (n = 30) male and 48.28% (n = 28) female. Of the specimens with known age at death (91%; n = 53), the minimum age was 18 years and maximum 86 years with a mean age of 47 (±15.52) years.

3.2. Morphometric measurements

The morphometric measurements obtained are presented in Table 1, including mean values, standard deviations. The spinous process angles (SPA) as depicted and inferior articular facet orientation (IAFO) and superior articular facet orientation (SAFO) are measured in degrees, and spinous process length (SPL), inferior articular facet width (IAFW) and superior articular facet width (SAFW) in millimeters. As left and right structures were measured, these are denoted as _L for left and _R for right followed by the vertebral level. These values were utilized for comparison in specimens demonstrating spinous process deviations to determine if any pattern could be determined. All metric measurements, fell within the calculated mean, and no pattern could be determined to suggest an association.

3.3. Frequency of upper thoracic spinous process deviations

Initial analysis of results was focused on the frequency per spinal level and sex in the entire vertebral sample group, and which region of the spinous process demonstrated deviations, as indicated in Table 2. Overall, the frequency ranges from 19% (n = 11) at T1 to 41.4% (n = 24) at T3, with males showing a higher frequency at all levels compared to females.

The distal spinous process deviations were the most common at all spinal levels. Of the overall spinous process deviations noted (n = 90), 45.56% (n = 41) were left distal deviations and 50% (n = 45) right distal deviations and 4.44% (n = 4) being proximal deviations, with males showing higher frequencies than females.

This global figure of frequency within the entire sample was then refined to determine the frequency of spinous process deviations within an individual's T1-T6 sequence (Table 3), with males showing higher

Table 2
Cross tabulation and frequency of upper thoracic spinous process deviation per sex.

				None	Distal left	Distal right	Proximal left	Proximal right	Total
T1	Sex	Male	Count	24	2	4	0	0	30
			% within sex	80.0%	6.7%	13.3%	0%	0%	100%
		Female	Count	23	1	4	0	0	28
			% within sex	82.1%	3.6%	14.3%	0%	0%	100%
	Total	Count		47	3	8	0	0	58
		% total		81.0%	5.2%	13.8%	0%	0%	100%
T2	Sex	Male	Count	16	6	8	0	0	30
			% within sex	53.3%	20.0%	26.7%	0%	0%	100%
		Female	Count	24	3	1	0	0	28
			% within sex	85.7%	10.7%	3.6%	0%	0%	100%
	Total	Count		40	9	9	0	0	58
		% total		69.0%	15.5%	15.5%	0%	0%	100%
T3	Sex	Male	Count	15	6	9	0	0	30
			% within sex	50.0%	20.0%	30.0%	0%	0%	100%
		Female	Count	19	7	2	0	0	28
			% within sex	67.9%	25.0%	7.1%	0%	0%	100%
	Total	Count		34	13	11	0	0	58
		% total		58.6%	22.4%	19.0%	0%	0%	100%
T4	Sex	Male	Count	22	3	4	0	1	30
			% within sex	73.3%	10.0%	13.3%	0%	3.3%	100%
		Female	Count	24	2	2	0	0	28
			% within sex	85.7%	7.1%	7.1%	0%	0.0%	100%
	Total	Count		46	5	6	0	1	58
		% total		79.3%	8.6%	10.3%	0%	1.7%	100%
T5	Sex	Male	Count	21	4	3	0	2	30
			% within sex	70.0%	13.3%	10.0%	0%	6.7%	100%
		Female	Count	24	2	2	0	0	28
			% within sex	85.7%	7.1%	7.1%	0%	0%	100%
	Total	Count		45	6	5	0	2	58
		% total		77.6%	10.3%	8.6%	0%	3.4%	100%
T6	Sex	Male	Count	21	4	4	0	1	30
			% within sex	70.0%	13.3%	13.3%	0%	3.3%	100%
		Female	Count	25	1	2	0	0	28
			% within sex	89.3%	3.6%	7.1%	0%	0.0%	100%
	Total	Count		46	5	6	0	1	58
		% total		79.3%	8.6%	10.3%	0%	1.7%	100%

Table 3
Spinous process deviations frequency T1-T6.

Humans (n = 58)	Sex	Male (n = 30)	Count	25
			% within sex	83.33%
		Female (n = 28)	Count	19
			% within sex	67.86%
	Total		Count	45
			% total	77.59%

frequencies than females, and an overall higher incidence than in the entire sample.

3.4. Age comparisons for frequency of spinous process deviations

Age as a factor that may influence the frequency of spinous process deviations was a consideration, and as such this information was included in the analysis.

Age ranges were allocated for specimens with known age at death, as indicated in Table 4, and demonstrated a frequency of 11.32% (n = 6) within the 51–60 years to 22.65% (n = 13) in the 31–40 years sample.

4. Discussion

4.1. Spinous process alignment and static palpation

Studies on the reproducibility of static palpation specifically relating to palpation for alignment of a structure is limited compared to inclusion of motion, and tenderness, however it is still presented as an included measure when assessing spinal regions to determining the diagnosis of a manipulable lesion. The data presented in the current study suggest that spinous process deviations as an osseus feature are not common in terms of an overall occurrence in the upper thoracic spine, but when evaluated within an individual, may be considered normal variations of this structure and a potential patient would have a significant probability of having at least one vertebra presenting with this feature. This would imply that manual therapists are likely to find evidence of spinous process deviation on examination utilizing palpation and may make the incorrect assumption of this being clinically relevant if viewed in isolation.

Stochkendahl et al. (2006) concluded that when critically reviewing literature regarding reproducibility of manual examination techniques of the spine, that pain or tenderness has an acceptable reproducibility, but that static palpation does not have clinically reproducible results both in terms of intra examiner and inter examiner evaluation. Similarly, Haneline and Young (2009) reviewed literature specifically related to static palpation of the spine and found reported indices of reliability are generally low, but that studies that reported on pain reproduction had higher levels. Beynon et al. (2018) additionally suggest that static palpation demonstrated moderate reliability for the identification of thoracic spine stiffness and tenderness, with tenderness demonstrating higher reliability. The findings in this study therefore add to the evidence that static palpation in isolation should not be considered as a technique for diagnosis of manipulable lesions, and gives further evidence that the concept of misalignments of joints are not appropriate in manual therapy.

Table 4
Spinous process frequency per age range and sex.

Age range (years)			
19-30 (n = 8)	Male (n = 2)	Count with SPD	2
		% with SPD	100%
	Female (n = 6)	Count	3
		% with SPD	50%
Total		Count with SPD	5
		% total SPD	62.5%
		% total with SPD for entire group (n = 53)	15.09%
31-40 (n = 13)	Male (n = 10)	Count with SPD	9
		% with SPD	90%
	Female (n = 3)	Count with SPD	3
		% with SPD	100%
Total		Count with SPD	12
		% total SPD	93.3%
		% total with SPD for entire group (n = 53)	22.65%
41-50 (n = 11)	Male (n = 8)	Count with SPD	7
		% with SPD	87.5%
	Female (n = 3)	Count with SPD	1
		% with SPD	33.33%
Total		Count with SPD	8
		% total	72.72%
		% total with SPD for entire group (n = 53)	15.09%
51-60 (n = 10)	Male (n = 3)	Count with SPD	3
		% with SPD	100%
	Female (n = 7)	Count with SPD	3
		% with SPD	42.85%
Total		Count with SPD	6
		% total with SPD	60%
		% total with SPD for entire group (n = 53)	11.32%
>60 (n = 11)	Male (n = 4)	Count with SPD	4
		% with SPD	100%
	Female (n = 7)	Count with SPD	5
		% with SPD	71.43%
Total		Count with SPD	9
		% total with SPD	81.81%
		% total with SPD for entire group (n = 53)	16.98%

Key: SPD = spinous process deviation.

4.2. Age related factors in spinous process deviation

This sample group is considered to be a fair representation of the overall Raymond A. Dart Collection of Human Skeletons, as this current study's age range of 18–86 years is similar to that presented by Dayal et al. (2009) of between 20 and 70 years of age. In this current study, although the sample size is small, age did not appear to be a determining factor for the presentation of spinous process deviation in either males or females. It may have been anticipated that age related degenerative changes in the spine would have the potential to alter vertebral morphology (Adams and Hutton, 1980; Brown et al., 2008) and studies related to SPD in humans, have generally focused on the lumbar spine, rather than the thoracic spine as was done in this current study, with the implication of SPD being associated with disc degeneration (Lewit, 1957; Ravichandrin, 1983; Van Schaik et al., 1989) or ageing (Aylott, 2012).

In addition to spinous process deviation's frequency related to age, spinous process deviations and articular width were compared, as mechanical changes in the facet joints have been associated with degeneration and osteoarthritis (Panjabi et al., 1993; Du et al., 2016) with facet joint hypertrophy being a recognized component of the degenerative changes associated with spondylosis of the spine (Weishaupt et al., 1999; Kalichman and Hunter, 2007). Wilde et al. (1988) observed that degenerative changes of the intervertebral disc can cause an abnormal burden in the moving segment accompanied by unilateral facet joint osteoarthrosis as a result of imbalance of the muscle attachments due to the SPD (Lewit, 1957; Tang et al., 2015). Yong-Hing and Kirkaldy-Willis (1983) proposed the three joint complex, made up of the two facet joints and the intervertebral disc at an intervertebral level, whereby a biomechanical relationship exists and degenerative changes in one of the three joints, will ultimately result in all joints being affected.

Given these observations, this study proposes that spinous process deviations may be associated with altered/asymmetrical loading of the spinous process. This may then result in a commensurate change in size (hypertrophy) of the associated articular facet width (as an indicator of degenerative change). For example, if the spinous process deviation was

to the right, was there an indication of right or left hypertrophy in the related articular facets? To assess this, the mean values of facet width with spinous process deviations were compared to the overall sample group's measurements of facet width means. All measurements were within the standard deviations' ranges indicating that they were most likely within the normal variation range if compared to variances. When evaluating the specimens visually, the presentation was not consistent, i.e. where articular facet degeneration and an increase in facet width were noted, spinous process deviations were not necessarily present. In other specimens, degenerative changes of the vertebral body also did not result in facet degenerative changes, and in some specimens unilateral articular facet degeneration and width change occurred without spinous process deviation (Fig. 9).

This would suggest that articular facet degeneration and ageing in the upper thoracic spine are not associated with spinous process deviations (as proposed in the lumbar spine) or alternatively that loading of the spinous process as a mechanism of spinous process deviation development is not significant enough to have an effect on the articular facet joint. Similarly, although in the lumbosacral region, Tang et al. (2015) concluded that no correlation was found between degeneration of the disc and spinous process deviation.

4.3. Handedness as a factor in spinous process deviation development

A proposed mechanism for the direction of spinous process deviations, could be the handedness of individuals, which may result in asymmetrical patterns of loading on the spinous process due to the increased motion or muscular loading toward the dominant hand side. Raymond et al. (1996) estimates that 10–13% of the human population are left-handed. In this current study, spinous process deviation directions in the sample were almost equal (11.7% left distal, and 12.9% right distal). This suggests that handedness is not a significant factor in SPD development. If handedness was a significant factor in spinous process deviation direction, significantly more spinous processes should have been deviated to the right.

4.4. Strengths and limitations

Few studies have utilized osteologic samples with images as a direct measure of anatomical variations in the upper thoracic spine. The methods presented validity and reproducibility outlined allow for a high level of confidence in the data presented with rigorous analysis and comparison, and extensive discussion of various potential contributing factors being presented. Manual therapists are often taught static palpation methods with little evidence suggesting validity, and this study highlights the need to ensure various approaches to determining where manipulable lesions are present should be utilized given the potential high rate of anatomical variations present within the upper thoracic spine.

Despite these strengths, there are certain limitations that need to be noted. The sample size was a limiting factor, and it is recommended that this be increased to allow for more comparison for the normal variability proposed in this study, and generalization to the larger population. The study was also not designed as a true incidence study where randomization of the sample would be required, and samples were selected randomly based on the inclusion criteria, but collections utilized were not randomized. Future research should also consider selection of samples that demonstrate spinous process deviations and evaluate morphometric measurements in relation to this feature being present which would facilitate an understanding of the correlation between spinous process deviation in terms of mechanical stresses or pathologies.

5. Conclusions

Spinous process deviations in the upper thoracic spine may be the result of random normal variations between individuals. The development of this feature does not appear to be associated with degenerative changes and ageing or handedness and is more frequent in males than females at all spinal levels. Static palpation utilizing alignment of spinous processes without pain criteria as a means of determining manipulable lesions, is not a reliable diagnostic technique in the upper thoracic spine, as this appears to be a normal osseous anatomical variation.



Fig. 9. Selected variations of degenerative changes noted in facet and intervertebral disc related to spinous process deviations. A: bilateral facet degeneration, limited IVD degeneration, no spinous process deviations; B: IVD degeneration, normal facet, no spinous process deviations; C: unilateral facet and IVD degeneration, no spinous process deviations.

6. Clinical relevance

- Alignment differences determined on static palpation of spinous processes may be as a result of normal anatomical variation.
- Tenderness should be included in static palpation as alignment alone is not an adequate determining feature of a manipulable lesion.

CRediT authorship contribution statement

Christopher Yelverton: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Validation, Visualization, Writing – original draft, Writing – review & editing. **Bernhard Zipfel:** Conceptualization, Methodology, Supervision, Writing – review & editing. **Scott Williams:** Conceptualization, Methodology, Supervision, Writing – review & editing. **Cynthia Peterson:** Writing – review & editing.

Declaration of competing interest

There are no conflicts of interest related to this paper.

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