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Anthropometric Analysis of the Cervical Spine

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ANTHROPOMETRIC ANALYSIS OF THE CERVICAL SPINE

A thesis submitted in partial fulfillment
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Master of Science in Engineering

By

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I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY Susan Laura Hueston ENTITLED Anthropometric Analysis of the Cervical Spine BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF Masters of Science in Engineering

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ABSTRACT

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An understanding of the dimensional anatomy of the cervical spine is necessary in order to help diagnose disease, deformity, injury, and device development. Previous investigation has been completed utilizing cadavers, X-rays and other imaging techniques. This research utilized computer tomography images from the trauma registry at Miami Valley Hospital in Dayton, Ohio to complete an anthropometric study of the cervical spine. Linear mathematical models were developed to investigate the relationships present in the dimensional anatomy of the cervical spine. New measurements were completed on subjects of both Caucasian and African American descent and of both genders. An approximation of the moment of inertia for the vertebral body was developed along with a computer program to predict anthropometric features. Statistical analysis on published data revealed 128 of 3000 and 133 of 2760 comparisons were significant. Similar trends were found to the measurement carried out with the CT data for this research.

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INTRODUCTION

The spine supports the skull and trunk, protects the spinal cord, and helps absorb stress that is produced from movement of the body (KenethS. Saladin PhD 2004). It also provides an attachment for the extremities, thoracic cage, and muscles (KenethS. Saladin PhD 2004). It consists of five sections: cervical, thoracic, lumbar, sacrum, and coccyx (KenethS. Saladin PhD 2004). There are a total of 33 vertebrae in the spine, in particular there are 7 in the cervical spine (located in the neck), 12 in the thoracic spine (located in the mid-section, supporting the rib cage), 5 in the lumbar spine (located in the lower back), 5 in the sacrum (located at the base of the spine), finally 4 small vertebra in the coccyx (KenethS. Saladin PhD 2004).

Of particular interest for the Spine Research Group is the cervical spine. There are an estimated number of 6000 deaths as a result of injury to the cervical spine and around 5000 cases of quadriplegia each year (Moira Davenport 2010). Because the cervical spine houses many of the nerves involved with bodily functions including those involved with sensory movement, injury to this section of the spine can be serious and even life-threatening. In order to better assist injury that occurs to this region of the spine it is important to understand its anatomy. Several studies have been completed by performing quantitative measurements of this region of the spine, particularly for the Caucasian population. The objective of the study was to establish any linear mathematical relationships that may be present in the different morphometry in the cervical spine vertebrae. Investigating also the difference found with respect to race, gender, and age of the subject. Furthermore it was of interest to establish an estimate of the mass moment of inertia of the vertebral body.

LITERATURE REVIEW

As stated previously, numerous studies have been completed investigating the morphometry of the spine. Included in these investigations have been cadaveric studies, as well as various CT/MRI/X-ray studies. In this section a review of the previous studies performed is discussed.

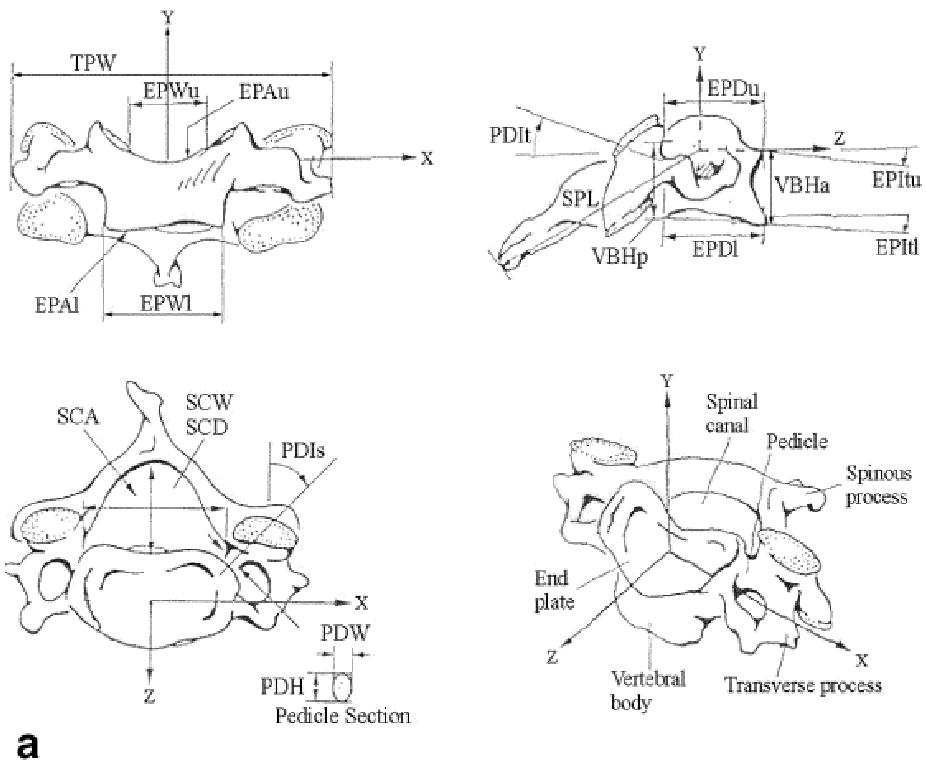
Cadaver Studies

Previous studies investigated the three-dimensional morphometry of the spine. Several of these studies investigated different races, particular sections of the spine, gender, or particular areas of the vertebra itself.

The different ethnicities included in the morphometric analyses were: Chinese Singaporeans, South Africans, African Americans, and Caucasians. The methods and actual measurements taken for these studies were not standardized and different approaches were taken in their investigations. However, similar measurements were taken for the Caucasian and Chinese Singaporean in two different studies.

Chinese Singaporeans:

Tan et al investigated Chinese Singaporean males between the ages of 50-70 years old. The spinal units were from the C3 to the L5 vertebrae (S.H. Tan 2004). The following measurements were included in their investigation: the upper and lower endplate width (EPWu and EPWl), the upper and lower endplate depth (EPDu and EPDl), posterior and anterior vertebral body height (VBHp and VBHa), spinal canal width and depth, (SCW and SCD), pedicle height on the left and right side (PDHl and PDHr), PL (pedicle length), spinous process length (SPL), transverse process width (TPW), upper and lower endplate area (EPAu and EPAl), spinal canal area (SCA), pedicle area on the left and right side (PDAl and PDAr), upper and lower endplate transverse inclination (EPItu and EPItl), pedicle sagittal inclination on the left and right side (PDIsl and PDIsr), and pedicle transverse inclination on the left and right side (PDItl and PDItr) (S.H. Tan 2004). These can all be seen in Figure 1.



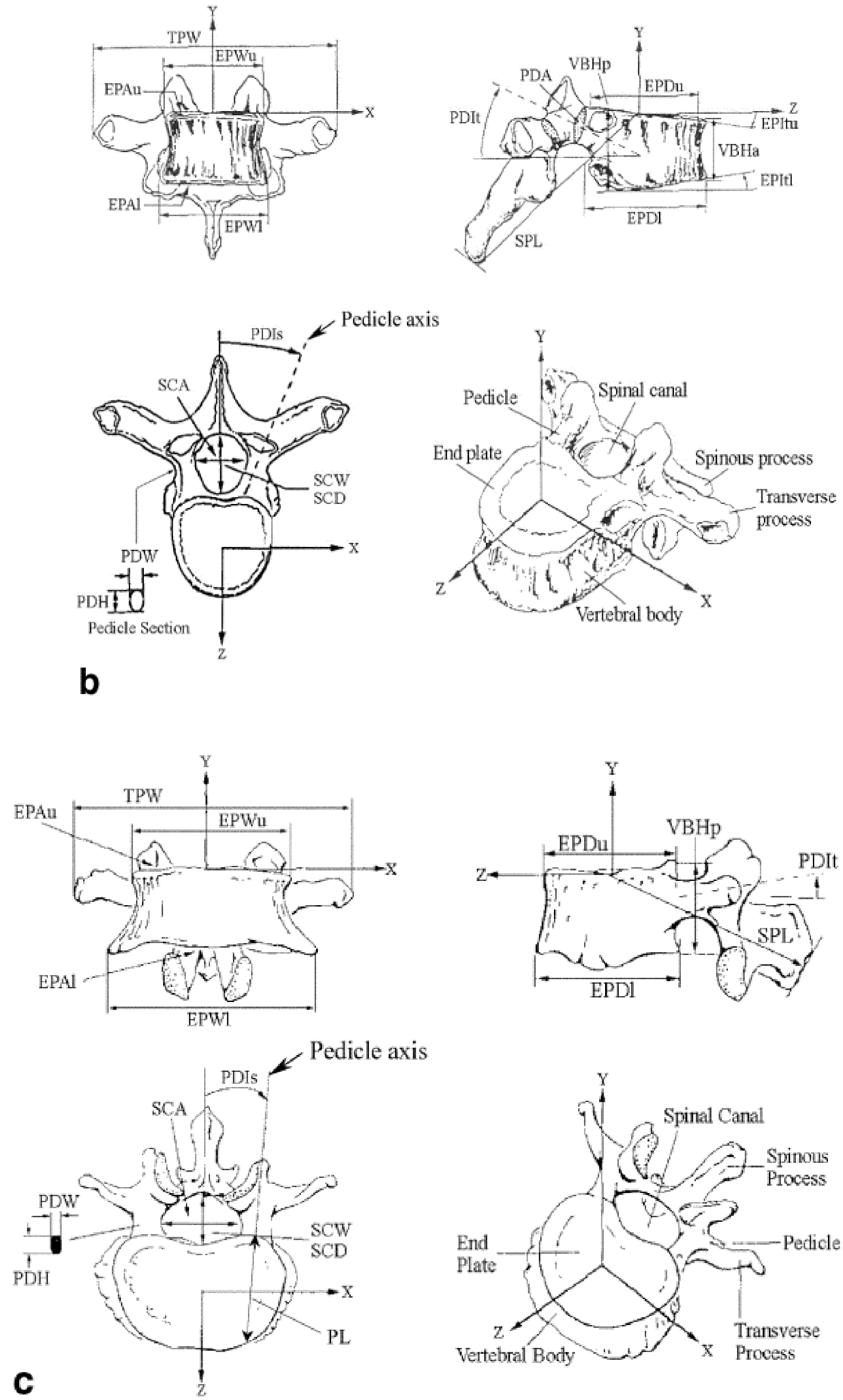


Figure 1: Chinese Singaporean Measurements – cervical spine (a), thoracic spine (b), and lumbar spine (c) (S.H. Tan 2004)

Before completing measurements the soft tissue was removed from the vertebrae and then immersed in a sodium hydrochloride solution for 30 minutes in order to dissolve the remaining remnants (S.H. Tan 2004). In order to remove the sodium hydrochloride spinal units were rinsed “under lukewarm water for” 20 minutes (S.H. Tan 2004). Finally, in order to limit the chance of the vertebra to deform they were “air dried and stored at a constant temperature and humidity (S.H. Tan 2004).”

The measurements were taken utilizing “a direct-contact, three-dimensional digitiser” that had an accuracy of 0.01 mm (S.H. Tan 2004). A direct contact probe was used in order to establish the coordinate system of the vertebra. This probe was then connected to a computer to collect the data and process it (S.H. Tan 2004).

As stated previously, the focus of this investigation has involved the cervical spine, as a result other regions of the spine will not be discussed. Tan et al found that the endplate width, depth, and vertebral body height remained relatively constant from C3 to C5 where it then increased (S.H. Tan 2004). The endplate width was found to increase more significantly than both the endplate depth and vertebral body height (S.H. Tan 2004). Also the VBHp, EPWl and EPDl were larger than the VBHa, EPWu and EPDu, respectively (S.H. Tan 2004). The SCW and SCD were fairly constant from C3 to C6 (S.H. Tan 2004). The SPL and TPW increase from C3 to C7 in a similar fashion (S.H. Tan 2004). The pedicle height on both the left and right side decreased from C3 to C6 and then increased gradually to C7 (S.H. Tan 2004). The pedicle width, on both the left and right side, increases through the cervical spine from C3 to C7 (S.H. Tan 2004).

The endplate area was found to increase through the spine as well from C3 to C7, with the upper always being larger than the lower (S.H. Tan 2004). Both the pedicle and spinal canal area remained fairly constant (S.H. Tan 2004). The endplate inclinations for both the upper and lower regions are angled toward the head with a steady inclination, and the EPItl was smaller than the EPItu (S.H. Tan 2004). The pedicle sagittal inclination (PDIs) was fairly constant at about 40° from C3 to C6, however at C6 the pedicles congregate towards each other (S.H. Tan 2004). The pedicle transverse inclination (PDIt) was angled towards the back from C3 to C4 and angle towards the head after C4 (S.H. Tan 2004)

Table 1: Chinese Singaporeans Measurement (S.H. Tan 2004)

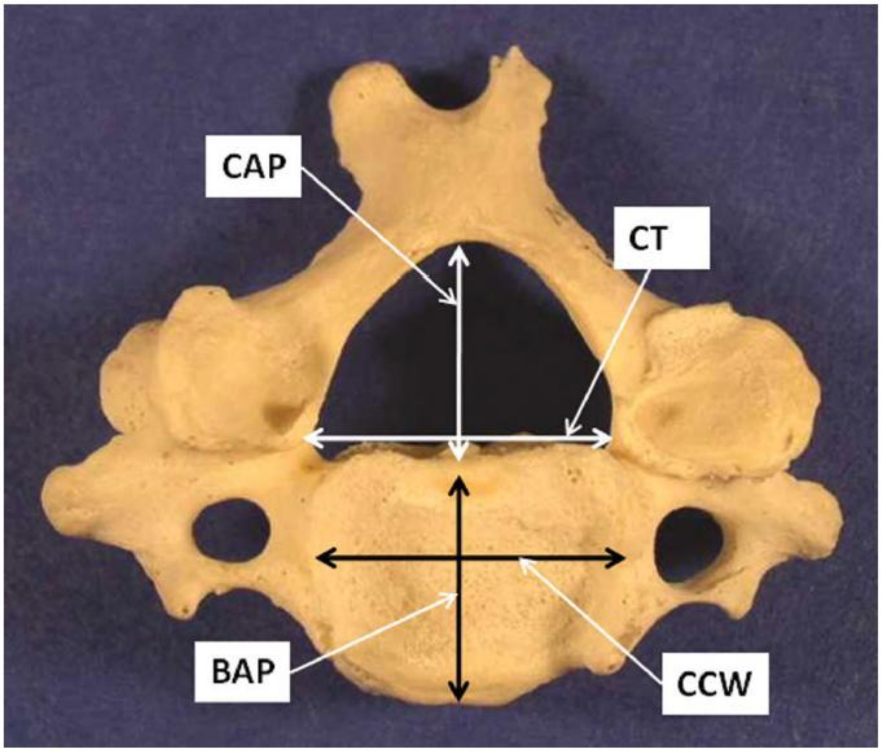
	C3		C4		C5		C6		C7	
	Mean	Std dev	Mean	Std dev	Mean	Std dev	Mean	Std dev	Mean	Std dev
EPWu	13.8	0.1	14.7	0.1	14.9	0.1	15.8	0	19	0.1
EPWl	14.3	0.1	15	0.1	15.9	0.1	19.5	0.2	20.3	0.2
EPDu	13.6	0.1	14	0.1	14.3	0.1	14.6	0.2	15.1	0.2
EPDl	15.1	0.2	15.2	0.4	15.1	0.3	15.7	0.3	15.6	0.3
VBHa	10	0.2	9.9	0.3	9.6	0.2	10.4	0.3	11.2	0.2
VBHp	11.2	0.1	11.3	0.2	11.3	0.1	11.3	0.2	11.8	0.3
SCW	19.2	0.4	19.3	0.5	20.3	0.4	20.6	0.4	19.7	0.4
SCD	10.3	0.3	10.3	0.3	10.3	0.3	10.3	0.3	11	0.2
PDHl	6.7	0.2	6.6	0.2	6.3	0.3	6	0.3	6.5	0.2
PDHr	6.8	0.2	6.7	0.2	5.9	0.2	6	0.1	6.1	0.1
PDWl	4.5	0.2	4.6	0.2	4.7	0.1	5.4	0.1	5.6	0.2
PDWr	4.4	0.2	4.5	0.2	4.9	0.2	5.4	0.2	5.7	1
SPL	25.6	0.5	30.3	0.4	33.6	1	40.5	1.5	46.9	1.1
TPW	41.4	0.8	44.9	0.8	47.6	1	48.4	0.9	53.8	1
EPAu	154.7	3.8	169.2	4.9	187.4	6.6	210.58	10	220.8	9
EPAl	216.8	10.1	241.5	10.6	286.4	10.3	316.3	7.4	340	10.3
SCA	149.7	9	159.9	8.4	166.8	8	163.7	10.2	167.5	6.7
PDAl	27.6	1	27.7	0.8	27.4	1.1	29.4	1.5	33.7	2.6
PDAr	28.5	1	28.8	1	28.5	1.1	33	1.3	32.1	1.6
EPItu	5	4.1	5.2	5.2	7.1	1.2	5.8	0.6	7.2	0.7
EPItl	3.3	0.5	3.5	0.7	2.7	0.3	4.2	0.4	5.1	0.5
PDIsl	-42.9	1	-44	1.3	-46.3	1	-41.9	1.6	-30.6	1.1
PDIsr	39.6	1	38.9	1.1	39.1	1.6	38.5	2.3	30.3	0.9
PDItl	-4.8	1	-3.2	0.7	2.6	0.7	4.8	1	5.8	0.7
PDItr	-6.5	1	-5.4	1.1	4.9	1	6	1.3	3.1	0.7

<u>South Africans</u>

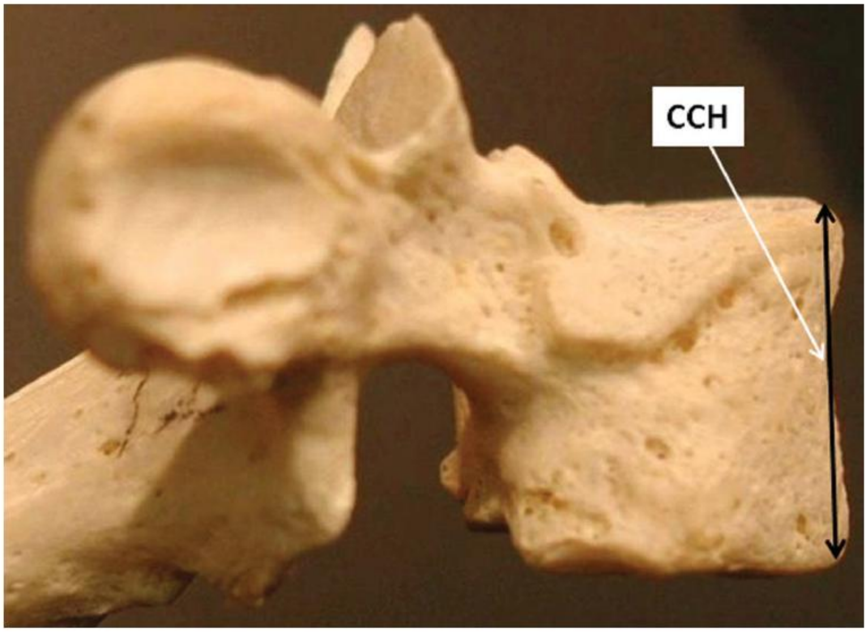
Kibii et al, investigated the differences in morphometry for three different subgroup of South Africans including White, Colored, and Zulu. Their study was limited, in that they only measured the C7 vertebra. The measurements included the

EPW, EPD, SCW, SCD, and VBHa and illustrated in Figure 2 (they used different acronyms of CCW, BAP, CT, CAP, and CCH respectively (Job M. Kibii 2010).

Kibii et al collected 240 cadaveric C7 vertebrae of both sexes, ranging from 30 to 70 years age group (Kibii). Of these 240 specimens: 120 were of Zulu origin with 60 of them being female and 60 being male; 60 were of White origin, with 30 being female and 30 being male; finally 60 of Colored origin, again with 30 being female and 30 male (Job M. Kibii 2010). Measurements were taken with the use of vernier calipers that had an accuracy of 0.01 mm (Job M. Kibii 2010). Their investigation included an analysis utilizing race and gender, and the correlations found were different morphometry, discussed below.



a.



b.

Figure 2: South African Measurements – axial view (a), sagittal view (b) (Job M. Kibii 2010)

Kibii et al found that for the White South Africans the SCD was larger in males than in females (Job M. Kibii 2010). The smallest SCD was seen in the Zulu male and Colored female subgroups (Job M. Kibii 2010). All together the females in the White and Colored subgroups had statistically significant smaller SCD than their male counterparts, but there was no significant difference found in gender in the Zulu subgroup (Job M. Kibii 2010). White males had statistically significant larger SCD than both the Colored and Zulu males (with no statistical difference found between the Colored and Zulu males) (Job M. Kibii 2010). Kibii et al also found that there was no statistical difference in the SCD among the subgroups for the female gender.

The largest SCW was found in the White subgroup, while the smallest were found in the Colored (Job M. Kibii 2010). All together the females of both Colored and Zulu group exhibited significantly smaller SCW than their male counterparts, while the White group had no statistically significant difference in regards to gender (Job M. Kibii 2010). Both the Zulu and White males had significantly larger SCW (with no statistical significant difference between the two) than the Colored males (Job M. Kibii 2010). White females exhibited significantly larger SCW than both the Zulu and Colored females (with no statistically significant difference between the two) (Job M. Kibii 2010).

The Colored subgroup displays the smallest EPD out of the three, while the Zulu males and White females have the largest EPD (Job M. Kibii 2010). Males of all three subgroups have statistically larger EPD's than their female counterparts (Job M. Kibii 2010). Colored males and females were found to have a significantly smaller EPD than both the Zulu and White males and females (with no significant difference found between the Zulu/White males and Zulu/White females) (Job M. Kibii 2010).

The largest VBHa was seen in the White group, while the Colored males and Zulu females had the smallest VBHa (Job M. Kibii 2010). Again the male gender of all subgroups displayed significantly larger VBHa than their female counterparts (Job M. Kibii 2010). White males and females were found to have significantly larger VBHa than both the Zulu and Colored males and females (with no significant difference between the Zulu/Colored males and Zulu/Colored females) (Job M. Kibii 2010).

As for the EPW, the largest was seen among the White group and smallest in the Colored (Job M. Kibii 2010). Again the male gender of all subgroups displayed significantly larger EPW than their female counterparts (Job M. Kibii 2010). Colored males had significantly smaller EPW than both the Zulu and White males (with no significant difference between these two) (Job M. Kibii 2010). Finally there were no significant differences found in subgroups in the female gender (Job M. Kibii 2010). Measurements found for this study are displayed in Table 2.

Table 2: South African C7 measurements

	SCD					
	Zulu		White		Colored	
	Male	Female	Male	Female	Male	Female
Mean	14.08	14.06	15.06	14.24	14.29	13.63
Std dev	1.43	1.62	1.34	1.42	0.9	1.04
	SCW					
	Zulu		White		Colored	
	Male	Female	Male	Female	Male	Female
Mean	24.37	22.9	24.77	24.25	23.48	22.45
Std dev	1.68	1.42	1.66	1.1	1.8	1.22
	EPD					
	Zulu		White		Colored	
	Male	Female	Male	Female	Male	Female
Mean	17.62	15.59	17.5	16.18	16.55	15.1
Std dev	1.74	1.31	1.65	2.06	1.3	1.55
	VBHa					
	Zulu		White		Colored	
	Male	Female	Male	Female	Male	Female
Mean	14.14	12.92	15.97	14.3	13.65	12.99
Std dev	1.34	0.86	2.96	1.18	0.87	0.79
	EPW					
	Zulu		White		Colored	
	Male	Female	Male	Female	Male	Female
Mean	28.03	25.18	28.34	25.52	26.98	24.86
Std dev	2.14	1.69	3.3	1.77	2.02	2.12

African Americans

There is very little investigation of this magnitude in the African American race in the United States. There have been several anthropometric studies that include this particular race but are for the lumbar or thoracic spine (Youssef Masharawi 2008; Peter V. Scoles MD 1988). A couple of studies even investigate estimating height of the subject based on length of a section of the spine (Donald R. Jason 1995; Tibbetts 1981).

One study that was found for the African American race (a second study that included an investigation in to both Caucasian and African American can be seen in the following section entitled Caucasians) and the morphometry of the cervical spine only included measurements of the spinal canal including the SCD and SCW (they used the acronyms CAP and CTR respectively) (Nancy E. Tatarek 2005). In this analysis Vernier calipers were used and the measurements were rounded to the nearest millimeter (Nancy E. Tatarek 2005). Measurements were completed on 321 skeletal subjects where 80 were African American males, 73 African American females, 80 Caucasian males, and 88 Caucasian females (Nancy E. Tatarek 2005). It was found that for both races and genders the SCD appeared largest in the C2 vertebra level, but generally males were larger than females (Nancy E. Tatarek 2005). In the C3 vertebra the SCD was fairly similar for both races and gender (Nancy E. Tatarek 2005). The African American race exhibited the smallest SCD in the C4 vertebra, while the Caucasian race exhibited the smallest in the C6 vertebra (Nancy E. Tatarek 2005). Tatarek et al found that the largest SCW was in the C6 vertebra, and generally it increased from C2 to C7. The SCW was generally 10 mm larger than the SCD for all subjects (Nancy E. Tatarek 2005). The measurements completed for this study are displayed in Table 3.

Table 3: African American Spinal Canal Measurements (Nancy E. Tatarek 2005)

		SCD				SCW			
		African American		Caucasian		African American		Caucasian	
		Male	Female	Male	Female	Male	Female	Male	Female
C2	Mean	16.4	15.09	16.8	16.61	23.39	22.52	23.79	22.9
	Std. Dev	1.31	1.57	1.54	1.14	1.23	1.39	1.47	1.51
C3	Mean	14.43	13.33	15.02	14.44	23.32	22.68	23.43	22.48
	Std. Dev	1.2	1.37	1.34	1.39	1.22	1.34	1.35	1.31
C4	Mean	13.98	13.16	14.58	13.73	24.31	23.47	24.13	23.47
	Std. Dev	1.32	1.44	1.33	1.34	1.23	1.48	1.46	1.29
C5	Mean	14.12	13.28	14.5	13.61	25.02	23.98	24.86	24.2
	Std. Dev	1.22	1.31	1.42	1.26	1.36	1.46	1.6	1.28
C6	Mean	14.25	13.32	14.26	13.39	25.46	24.49	25.21	24.32
	Std. Dev	1.13	1.29	1.37	1.08	1.44	1.6	1.65	1.41
C7	Mean	14.37	13.57	14.33	13.42	24.48	23.53	24.33	23.41
	Std. Dev	0.97	1.21	1.41	1.07	1.31	1.35	1.61	1.33

<u>Caucasian:</u>

There have been several studies completed on the Caucasian race and the morphometry of the cervical spine. A study completed by Panjabi et al included 12 cadaveric spines. The subjects ranged from 19-59 years old with an average of 46.3 years, and 8 males and 4 females (Manohar M. Panjabi 1991). Before measurements were taken all soft tissue was removed from the vertebrae. A specially designed morphometer was used to assist in measurements taking. This instrument included "one linear variable (LVDT) and two rotational variable (RVDT) displacement transducers arranged such that their axes met at one point," this established a spherical coordinate system (Manohar M. Panjabi 1991). The measurements were then directly recorded on a computer (Manohar M. Panjabi 1991). The measurements investigated were similar to what was established earlier in the investigation of the Chinese Singaporean race by Tan except excluding the VBHa and PL, and including upper and lower uncovertebral joint inclination in the frontal plane (UJIfu and UJIfl), upper and lower uncovertebral joint inclination in the sagittal plane (UJIsu and UJIsl), upper and lower uncovertebral joint area on the right side (UJAru and UJArl), and the upper and lower uncovertebral joint area on the left side (UJAlu and UJAll) (Manohar M. Panjabi 1991). These measurements are displayed in Figure 3.

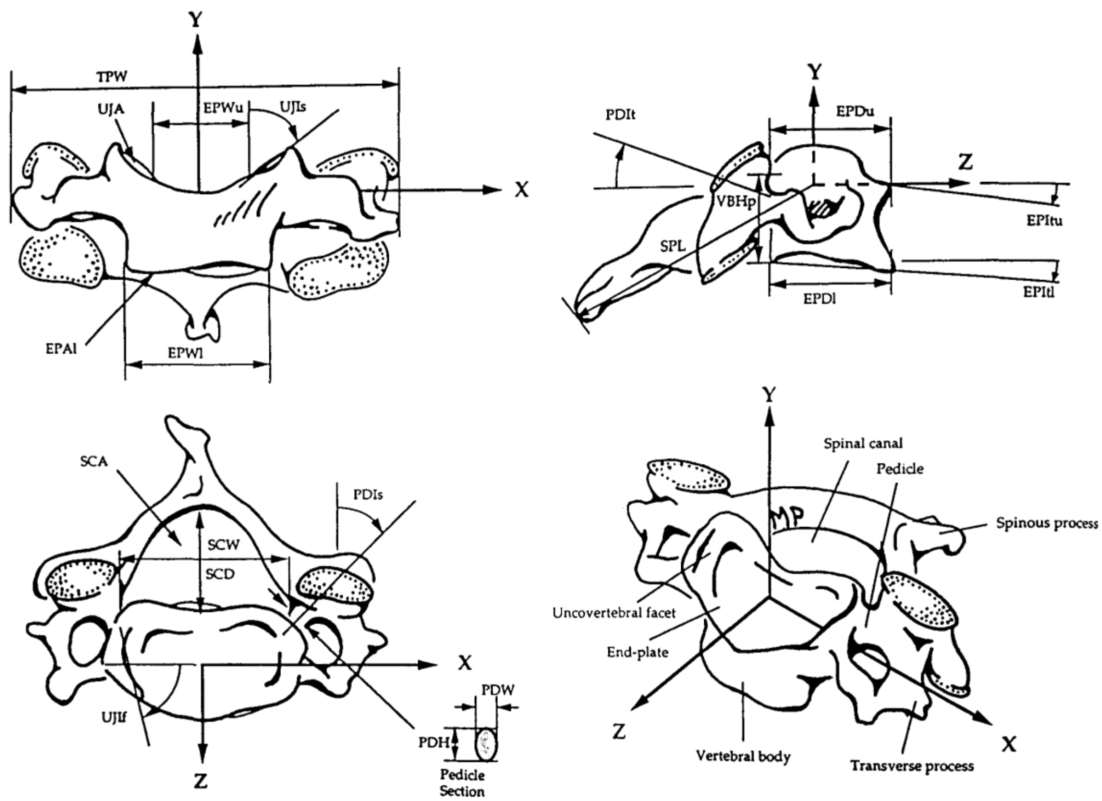


Figure 3: Caucasian Measurements – Panjabi (Manohar M. Panjabi 1991)

Panjabi et al found that the EPW and EPD increased from C2 to C7, and the widths were always greater than the analogous depths. The EPAu was found to increase from C2 to C7, while the EPAl increased from C2 to C3 and from C6 to C7

(Manohar M. Panjabi 1991). As an approximation of these areas they found that an elliptical approximation of the EPA was “justified (Manohar M. Panjabi 1991).” The VBHp was found to be fairly constant from C3 to C7 (Manohar M. Panjabi 1991). Investigation into the spinal canal measurements exhibited that the SCW was significantly larger than the SCD (Manohar M. Panjabi 1991). The SCW remained fairly constant from C2 to C7, the SCD though decreased from C2 to C3 where it then remained constant until C6 where there was a decrease into C7 (Manohar M. Panjabi 1991). The SCA was largest at C2 and smallest at C7 (Manohar M. Panjabi 1991). The pedicle parameters: width and height on both the left and right side were larger at C2 and smallest at C3, thereafter, there is an increase into C7 (Manohar M. Panjabi 1991). The PDH is significantly larger than the PDW, thus creating an elliptical cross section (Manohar M. Panjabi 1991). The SPL decreased from C2 into C3 but then remains constant through C5, where it then increases into C7 (Manohar M. Panjabi 1991). The TPW increases superiorly-inferiorly through the cervical spine (Manohar M. Panjabi 1991). The upper uncovertebral joint area is approximately two times larger than the lower (Manohar M. Panjabi 1991). The UJIf increases from C5 to C7, while the UJIs remains constant through the cervical spine (Manohar M. Panjabi 1991). The measurements described previously that were completed by Panjabi are displayed in Table 4.

Table 4: Caucasian Measurements – Panjabi (Manohar M. Panjabi 1991)

	C2		C3		C4		C5		C6		C7	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
EPDu	------	------	15	0.55	15.3	0.75	15.2	0.35	16.4	0.52	18.1	0.66
EPWu	------	------	15.8	0.46	17.2	0.66	17.5	0.58	18.5	0.55	21.8	0.66
EPDl	15.6	0.58	15.6	0.4	15.9	0.38	17.9	0.52	18.5	0.69	16.8	0.32
EPWl	1.5	0.52	17.2	0.29	17	0.49	19.4	0.4	22	0.75	23.4	0.98
VBHp	------	------	11.6	0.35	11.4	0.43	11.4	0.32	10.9	0.26	12.8	0.46
EPAu	------	------	169.4	8.78	183	9.32	182.9	7.77	221.2	7.62	278.3	12.93
EPAl	194.4	9.64	190.7	5.74	199.2	7.27	246.2	12.07	289.9	16.54	280.3	13.71
EPItu	------	------	2.7	0.77	3.5	1.5	1.7	0.43	4.7	1.1	2.2	0.54
EPItl	4.2	1.2	4	0.84	2.1	0.4	2.7	1.1	2.7	0.69	1.8	0.42
SCW	24.5	0.61	22.9	1.15	24.7	0.52	24.9	1.13	25.8	0.66	24.5	0.92
SCD	21	0.35	16.2	1.33	17.7	0.46	17.4	0.72	18.1	0.46	15.2	1.15
SCA	374.5	13.08	248.7	34.21	272	26.18	249.5	34.09	266.5	24.94	223.8	36.26
PDWr	7.7	0.35	5.8	0.64	5.7	0.6	6.1	0.46	6.3	0.49	6.6	0.42
PDHr	9.4	0.46	7.6	0.46	7.4	0.42	6.7	0.42	7.1	0.39	7.5	0.32
PDWl	8.3	0.07	5.4	0.32	5.1	0.46	5.1	0.35	5.6	0.39	6.5	0.35
PDHl	11.1	0.14	7.2	0.35	7.3	0.49	7.3	0.39	7.5	0.32	7.5	0.28
PDAr	32.3	2.44	24.2	2.69	24.7	2.65	23.8	2.83	24.5	2.58	30.4	3.08
PDAl	51.8	0.28	21.4	2.02	24	3.08	23.9	2.58	27.9	2.47	27.8	2.37
PDIsr	------	------	41.6	1.13	44.6	1.66	39.3	4.45	29.6	2.3	33.1	2.23
PDItr	------	------	-9.2	2.58	-8.6	2.44	-6.3	1.63	7.1	1.13	13.4	1.7
PDIsl	------	------	42.9	2.16	43.9	2.47	41.2	4.77	34.1	2.16	26.7	2.69
PDItl	------	------	-7.1	0.67	-6.5	1.66	-5.7	1.48	5.9	2.51	9.2	1.52
SPL	33.7	1.39	29.6	0.78	30.3	1.07	28.5	0.98	34.2	1.88	45.7	0.84
TPW	52.6	2.08	50.3	1.62	48.5	2.14	46.4	2.97	49.5	2.11	66.6	1.13
UJAru	------	------	46.7	4.27	40.9	3.18	45.3	6.09	48.8	3.32	43.1	3.84
UJAlu	------	------	40.5	3.95	37	3.41	40.4	4.73	58.1	7.45	41.2	3.15
UJArl	19.8	3.7	22.6	2.51	25.5	3.26	27.2	2.94	25.6	2.66	23.4	2.71
UJAll	17.7	2.4	22.3	2.89	23.5	1.96	30.5	3.84	23.9	1.79	19	3
UJIfu	------	------	76.6	2.22	76.2	2.45	82.7	1.44	104	2.4	115.6	2.68
UJIsu	------	------	38.7	3.87	40	2.89	34.5	2.08	40.8	3.52	47.3	3
UJIfl	78.4	3.2	81.6	1.59	83.5	1.39	84.9	1.1	106.2	2.28	113.4	2.17
UJIsl	63.7	5.05	47.8	4.01	47.8	3.46	45	3.03	49.2	4.33	59.8	4.47

Francis also studied the morphometry of the cervical spine including both genders, and of both Caucasian and African Americans. In this study 100 Caucasian male cadaveric spines were used that ranged from the ages of 25-36 years old, 100 African American male cadaveric spines from 25-34 years of age, 27 Caucasian female between the ages of 25-36 years, and 57 African American females between the ages of 25-36 years (Francis 1955). The measurements included in this study include TPW, SCD, SCW, VBHp, EPDl, EPWl, along with the total anteroposterior diameter of the vertebra (Francis 1955). This study found that there was no significant difference in the size of the vertebra between races of both genders (Francis 1955). It was stated that the females of both races were smaller than their counterparts, but there was no significant difference between male and female (Francis 1955). This is different than what has been found previously, with males generally being significantly larger than females. Table 5 displays the measurements completed by Francis.

Table 5: Caucasian Measurements – Francis (Francis 1955)

		Anteroposterior Diameter (mm)				VBHp			
		Caucasian		African American		Caucasian		African American	
		Male	Female	Male	Female	Male	Female	Male	Female
C1	Mean	47.1	42.5	47.5	44.4	17.5	16.6	16.7	15.9
	Std.Dev					1.7	1.7	1.6	1.5
C2	Mean	54.4	49	51.7	47.8	39.9	36.6	38.6	35.7
	Std.Dev					2.4	2	2.4	2.4
C3	Mean	46.2	43.1	45.4	42.1	14.3	12.4	13.7	12.3
	Std.Dev					1.2	0.9	1.1	0.9
C4	Mean	46.3	43	46	42	13.8	12.6	13.4	12.1
	Std.Dev					1.2	0.8	1.1	1
C5	Mean	48.2	43.9	49	44.5	13.3	11.9	12.6	11.6
	Std.Dev					1	1.1	1	1.1
C6	Mean	53.9	49.1	55.3	49.9	13	11.7	12.6	11.8
	Std.Dev					1.1	0.8	0.9	1
C7	Mean	62.6	56.3	63.2	56	14.6	13.2	14.6	13.2
	Std.Dev					1.1	1.2	1	1

Table 5: Caucasian Measurements – Francis part 2 (Francis 1955)

		TPW				EPDl			
		Caucasian		African American		Caucasian		African American	
		Male	Female	Male	Female	Male	Female	Male	Female
C1	Mean	81.4	73.3	76.8	69.8	12.2	11.1	11.8	10.8
	Std.Dev					1	0.9	0.8	0.9
C2	Mean	56.3	51.2	54.3	49.4	16.1	14.7	17.3	15.6
	Std.Dev					1.3	1.1	1.4	1.3
C3	Mean	54.9	50	53.3	48.9	16.4	14.7	17.3	15.5
	Std.Dev					1.3	1.2	1.4	1.1
C4	Mean	55.8	51.3	54.7	50.3	16.5	14.9	17.3	15.3
	Std.Dev					1.3	1.4	1.4	1.2
C5	Mean	57.5	53.2	56.7	52.1	16.8	15.4	17.2	15.5
	Std.Dev					1.4	1.6	1.4	1.2
C6	Mean	60.5	54.9	60	54.7	17.3	15.9	17.2	15.6
	Std.Dev					1.4	1.3	1.6	1.2
C7	Mean	72.4	65.4	70.2	64.5	16.7	14.9	16.8	15.2
	Std.Dev					1.3	1.2	1.5	1.2
		SCD				EPWl			
		Caucasian		African American		Caucasian		African American	
		Male	Female	Male	Female	Male	Female	Male	Female
C1	Mean	33.1	30.1	32.4	31.1	10.7	10.1	10.4	10
	Std.Dev	2	1.9	2.5	2.2	0.8	0.6	0.8	0.7
C2	Mean	22	20.7	20.2	20.1	19.5	17.9	20.3	18.6
	Std.Dev	1.9	2.1	2.1	1.9	1.7	1.5	1.2	1.4
C3	Mean	16.5	15.5	15.2	15.1	20.5	18.9	20.9	19.1
	Std.Dev	1.7	1.6	1.3	1.3	1.6	1.6	1.8	1.3
C4	Mean	15.4	14.8	14.8	14.5	21.5	19.6	21.4	19.8
	Std.Dev	1.5	1.2	1.3	1.4	1.1	1.5	1.8	1.3
C5	Mean	15.4	14.4	15.1	14.6	22.5	20.4	22	20.4
	Std.Dev	1.3	1.4	1.3	1.4	1.7	1.6	1.4	1.5
C6	Mean	15.4	14.1	15.2	14.4	24.8	22.5	24.4	22.3
	Std.Dev	1.4	1.4	1.3	1.3	1.9	1.9	1.6	1.4
C7	Mean	15.5	14.4	15.5	14.3	29.3	26.2	28.9	25.9
	Std.Dev	1.5	1.4	1.3	1.1	1.8	1.8	2	1.7

Table 5: Caucasian Measurements – Francis part 3 (Francis 1955)

		SCW			
		Caucasian		African American	
		Male	Female	Male	Female
C1	Mean	30.1	28.1	28.3	27.3
	Std.Dev	1.9	2.3	2.1	2.3
C2	Mean	24.5	23.1	24.1	23.4
	Std.Dev	1.6	1	1.6	1.4
C3	Mean	23.9	22.6	24.3	23.2
	Std.Dev	1.3	0.9	1.5	1.2
C4	Mean	24.7	23.7	25.2	24
	Std.Dev	1.3	1.3	1.5	1.1
C5	Mean	25.6	24.7	26	25
	Std.Dev	1.4	1.2	1.4	1.5
C6	Mean	25.9	25.1	26.4	25.3
	Std.Dev	1.4	1.6	1.7	1.4
C7	Mean	25.6	24.4	25.5	24.4
	Std.Dev	1.6	1.4	1.3	1.3

From these cadaver studies it was found that generally there was significant difference between genders in the morphometry of the cervical spine. There are mixed results with respect to race, some found no significant difference between race while others found significant difference based on the measurement. Other common findings found in the previous studies include that the SCW greater than the SCD, and the TPW and PDH increased through the cervical spine.

CT/MRI/X-ray Studies:

Several studies have also been reported examining the morphometry of the cervical spine through non-cadaveric methods, utilizing Computed Tomography (CT), Magnetic Resonance Imaging (MRI), or Radiographic (X-Ray) images. In these studies there has been less focus on race but have included some analysis on age and sex. No study was found similar to Panjabi and Tan. As a result, it is important to investigate spine morphometry further, especially for other non-Caucasian descent.

Liguoro on the French population utilized X-ray images to investigate the morphometry of the cervical spine with respect to age and gender. A sample size of 120 adults was used which included 69 male and 51 female, ranging from 20 to 80 years of age (D. Liguoro 1994). Lateral views of the cervical spine were used in this investigation, and a millimeter ruler was used to take measurements from X-ray images (D. Liguoro 1994). The measurements of the cervical spine that were included in this study for the upper cervical spine were: the anterior-posterior diameter (DAP in C1), thickness of the anterior arch (TAA in C1), thickness of the posterior arch (TPA in C1), total height of C2 (C2TH), anterior-posterior diameter of the inferior side of the vertebral body (DAP in C2) (D. Liguoro 1994). The measurements for the lower cervical spine that were included in this investigation were: VBHp, VBHa, the vertebral body height in the median (VBHm), EPDu, EPDl, antero-posterior diameter in the median (EPDm), height of the intervertebral disc (HIVD), total anterior height from C3 to C7 (THa), and total posterior height from C3 to C7 (THp) (D. Liguoro 1994). These measurements can be seen in Figure 4.

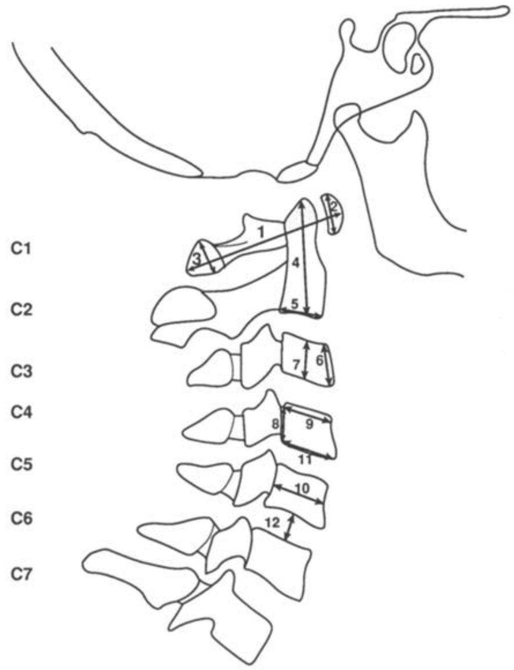


Figure 4: Measurements by X-ray – Liguoro*:* 1. DAP C1, 2. TAA, 3. TPA, 4. C2TH, 5. DAP C2, 6. VBHp, 7. VBHa, 8. VBHm, 9. EPDu, 10. EPDl, 11. EPDm, 12. HIVD, 13. THa, and 14. THp

Liguoro et al found that the vertebrae themselves were more wide than thick except for C7 which was roughly square. All measurements were significantly different when gender was compared (D. Liguoro 1994). The analysis completed on age divided the subjects into three different groups: 20-40 years, 40-60 years, and 60+ years. When the 20-40 group was compared to the 40-60 it was found that there was no statistical difference, along with the comparison between the 40-60 and the 60+, but there was significant difference found between the 20-40 and the 60+ age groups (D. Liguoro 1994). It was found that the disc HIVD decreased with age, which is known to be as a result of disc degeneration (D. Liguoro 1994; KenethS. Saladin PhD 2004). The DAP C2 was found to significantly increase in both genders as age progresses (D. Liguoro 1994). Measurements for this study are included and shown in Table 6, excluding the HIVD, THa, and THp for those values were not given in the article although was stated to have been accomplished.

Table 6: X-Ray Measurements – Liguoro (D. Liguoro 1994)

		C1	C2	C3	C4	C5	C6	C7
DAP	Male	55	19	---	---	---	---	---
	Female	51	16	---	---	---	---	---
TAA	Male	14	---	---	---	---	---	---
	Female	12	---	---	---	---	---	---
TPA	Male	11	---	---	---	---	---	---
	Female	10	---	---	---	---	---	---
C2TH	Male	---	43	---	---	---	---	---
	Female	---	39	---	---	---	---	---
VBHp	Male	---	---	17	16	16	16	17
	Female	---	---	15	15	14	14	15
VBHa	Male	---	---	16	15	15	15	16
	Female	---	---	14	14	13	13	15
VBHm	Male	---	---	15	14	19	15	15
	Female	---	---	13	13	16	12	14
EPDu	Male	---	---	18	19	19	20	21
	Female	---	---	16	16	16	18	18
EPDl	Male	---	---	20	20	21	21	20
	Female	---	---	17	17	18	19	18
EPDm	Male	---	---	19	19	14	19	20
	Female	---	---	16	16	13	17	18

Nissan et al studied 157 Caucasian males ranging from the ages of 20-38 years. All were taken from lateral X-Ray images, utilizing the same machine. The measurements included in this study were EPDl, VBHa, EPDu, VBHp, SPL, spinous process horizontal length (SPLh), anterior intervertebral disc height (HIVDa), posterior intervertebral disc height (HIVDp), and the vertebral body diagonal (VBd) (M. Nissan 1984). These measurements can be seen in Figure 5.

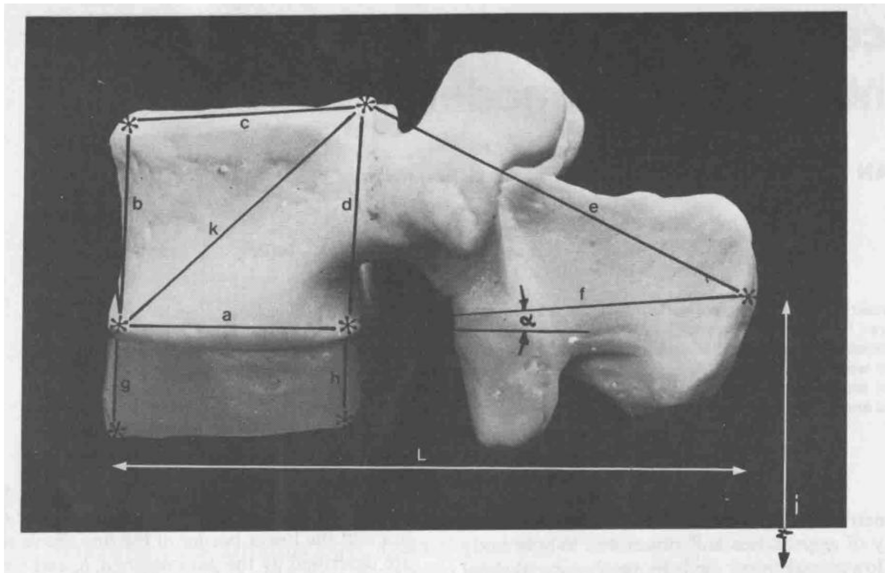


Figure 5: Measurements by X-Ray – Nissan*:* a. EPDl, b. VBHa, c. EPDu, d. VBHp, e. SPL, f. SPLh, g. HIVDa, h. HIVDp, and k. VBd.

Nissan et al found that the EPD increased superiorly to inferiorly through the cervical spine. The VBH was found to decrease from C2 to C5 but then increased into C7 (M. Nissan 1984). The SPL increased from C3 to C7, but C2 was significantly larger than C3 (M. Nissan 1984). The VBd was fairly constant throughout the cervical spine (M. Nissan 1984). Table 7 includes all measurements completed in this study by Nissan et al.

Table 7: X-Ray Measurements - Nissan

		C2	C3	C4	C5	C6	C7
EPDl	Mean	15.3	15.6	15.8	16.1	16.6	16.3
	Std. Dev	1.6	1.5	1.5	1.5	1.4	1.4
VBHa	Mean	19	14.1	13.4	12.7	13	14.6
	Std. Dev	3.2	1.3	1.3	1.3	1.3	1.4
EPDu	Mean	12.6	14.8	15.5	15.5	16	16.4
	Std. Dev	2.1	1.5	1.7	1.7	1.7	1.4
VBHp	Mean	16.6	14.5	13.9	13.8	13.9	14.9
	Std. Dev	2.5	1.4	1.2	1.4	1.6	1.4
SPL	Mean	40	34.4	33.6	35.4	41.5	49.6
	Std. Dev	3.5	3.1	2.8	3.1	4.6	3.5
SPLh	Mean	36.6	30.6	30.4	33	39.7	46.4
	Std. Dev	2.6	3	2.6	3.2	5	3.3
HIVDa	Mean	4.8	5.3	5.5	5.4	5.2	4.7
	Std. Dev	1	0.9	1	1	1	1.2
HIVDp	Mean	3.4	3.3	3	3	3.3	3.5
	Std. Dev	1	0.9	1	0.9	1	1.2
VBd	Mean	24.7	23.4	23	22.6	22.6	22.8
	Std. Dev	2.4	1.9	1.9	1.8	1.7	1.6

Other studies done for the cervical spine have been focused on measurement of the pedicle. One study investigated transpedicular screwing of the C7 vertebra, and testing the safety of a surgical technique that would only use posterior landmarks as guidance to placement of the screw (C. Barrey 2003). Studies have also been completed on the thoracic and lumbar regions in determining the safe zone for pedicle procedures (Shiu-Bii Lien 2007).

Rao et al studied 63 males, and 35 females of unknown race, with a mean age of 24.6 ± 5.7 years and 25.3 ± 6.1 years respectively. The measurements were taken of the lower cervical spine (C3-C7) on CT images and included: the pedicle length (PDL), pedicle axis length (PDXL), PDIt, PDIs, medial offset of the pedicle axis

(MOPD), PDH, PDW, and the sagittal offset of the pedicle axis (SOPD) (Raj D. Rao 2008). Figures 6-8 display these measurements.

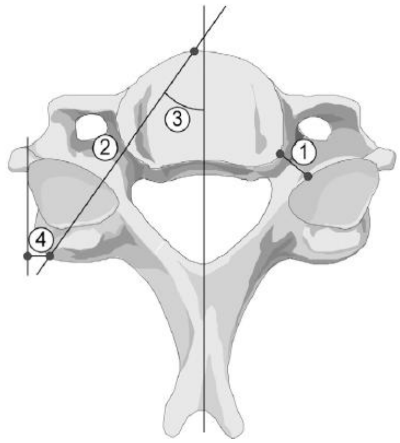


Figure 6: CT measurement, Axial – Rao*:* 1. PDL, 2. PDXL, 3. PDIs, 4. MOPD (Raj D. Rao 2008)

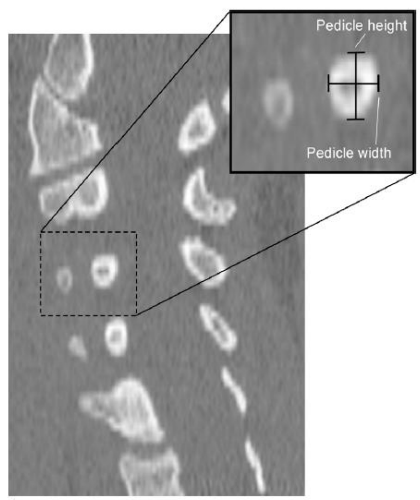


Figure 7: CT Measurement, Sagittal – Rao (Raj D. Rao 2008)

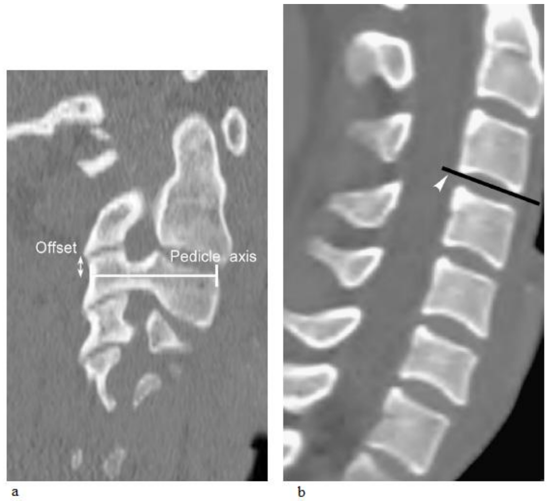


Figure 8: CT Measurement, Sagittal2 – Rao*:* a. Offset- SOPD b. PDIt (Raj D. Rao 2008)

Rao et al found that there was no statistical difference between the left and right side pedicles. They found that there was statistical significant difference between genders of all measurements except for the case of the PDIs (Raj D. Rao 2008). All measurements except PDIs were significantly dependent on sex and the vertebral level (Raj D. Rao 2008). The male gender exhibited larger measurements than the females in all cases (Raj D. Rao 2008). The PDH was larger than the PDW from C3-C5, but fairly equal at C6, and reversed in the C7 vertebra (Raj D. Rao 2008).

Table 8: CT Measurement – Rao (Raj D. Rao 2008)

		C3		C4		C5		C6		C7	
		Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev
PDH	Male	6.6	0.8	6.8	0.7	6.6	0.7	6.6	0.8	7	0.8
	Female	5.6	1	5.6	0.8	5.6	0.7	5.6	0.9	6	0.8
PDW	Male	5.8	0.9	6	0.8	6.3	0.8	6.5	0.8	7.6	1
	Female	4.8	0.9	5	0.8	5.2	0.8	5.7	0.8	6.5	0.9
PDL	Male	5.4	0.7	5.3	0.6	5.7	0.6	6	0.6	5.9	0.6
	Female	5.1	0.7	5.1	0.6	5.5	0.7	5.6	0.7	5.5	0.8
PDXL	Male	34.3	2.2	33.7	2.4	34.2	2.4	34.1	3.2	32.6	3.2
	Female	30.9	1.9	30.3	1.7	30.9	2.1	30.6	2.6	28.9	3.5
PDIs	Male	47.4	3.4	47.8	3.6	45.9	3.6	41.8	4.3	33.8	5.7
	Female	46.6	3.2	47.8	2.9	46.9	4.2	42.5	4.5	33	5.6
PDIt	Male	13.9	4.1	7.3	4.1	1.3	4.3	-2.6	4	-2.4	3.9
	Female	13.4	3.7	7.7	4.4	0.5	4.2	-3.3	3.5	-3.6	3.7
MOPD	Male	1.5	1	2.7	1.2	2.9	1.3	3.4	1.5	5.6	2
	Female	1.3	0.9	1.9	1	2	1.2	2.7	1.4	4.8	1.7
SOPD	Male	4.5	1.4	2.4	1	2	1	1.6	1	1.9	1.1
	Female	3.8	1	2.4	0.8	1.9	0.7	1.7	0.8	1.4	0.9

Previous studies have used CT MRI or X-Ray images to measure dimensional anatomy however they did not asses the differences in demographics of the subjects. One study did assess the effect of gender and age on dimensional anatomy. Specifically there was significant difference between the 20-40 age group and the 60+ age group, but no difference between the 20-40 and 40-60 age group and no difference between the 40-60 and 60+ age group (Nancy E. Tatarek 2005). Also in relationship with the pedicle morphometry it was found that it is greatly dependent on the spinal level (Raj D. Rao 2008). Aside from these previously stated studies there have been no studies investigating total 3D measurements through the use of CT scans. Furthermore there has been no investigation into racial parameters.

METHODS

Subjects:

The Institutional Review Board (IRB) protocol 10-0011 approved on 04/07/10 was obtained to investigate spinal morphometry. A total of 50 randomly selected subjects were utilized in this investigation, where 17 were female (5 African American, 12 Caucasian), and 27 were male (2 African American, 25 Caucasian). Subjects were also divided into age groups of 18-40 years (15 subjects), 41-60 years (12 subjects), and 61+ years (17 subjects). CT images were taken at Miami Valley Hospital in Dayton, Ohio through the year of 2010. Images were collected by Matt Binkley, MD, utilizing the guidelines presented in the IRB. The CT images were selected from the trauma registry, but the subjects used in this investigation did not include those with serious injury or with serious deformation in the cervical spine.

Measurements:

Three-dimensional measurements were taken from the CT images including all three views available when viewing images of this type, from the C3 to C7 vertebra. When investigating how measurements were taken in previous studies of this type, it was found that measurements were completed utilizing anatomical features, thus guiding the way measurements were completed in this investigation. All measurements were taken on the slice that provided the most “full” view of the vertebra, multiple measurements taken when possible. The slice thickness, in most cases was 2 mm, this had to be taken into account when measuring the details. All measurements were taken with the CT viewer provided for all subjects, the Centricity DICOM Viewer, Version 2.2 by GE Medical Systems, seen in Figure 9. The case numbers of the patients have been blocked in order to protect the identity of the subjects. This program was utilized to create the appropriate distance and angles.

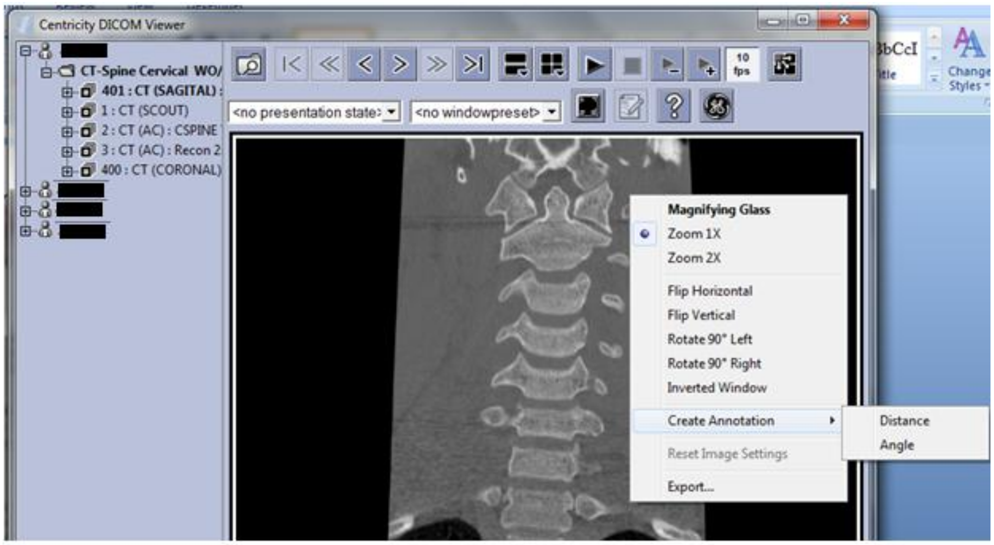


Figure 9: Program utilized to view CT's and complete measurements

The measurements completed in the coronal view, seen in Figure 10, were the EPWu and the EPWl. The EPWu was measured on the superior surface of the vertebra on the location of the upper endplate from one uncovertebral joint to the other. The EPWl was also measured in this view on the inferior surface of the vertebra from one side to the other (seen in Figure 10).

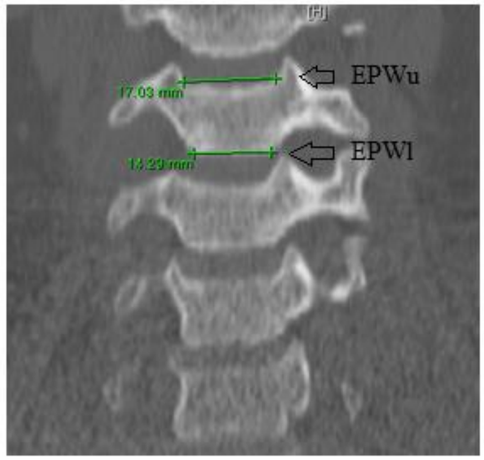


Figure 10: Coronal Measurements

In the sagittal view, seen in Figure 11, the VBHp, VBHa, EPDu, and EPDl were measured. The VBHp was measured on the posterior surface of the vertebra from the most superior-posterior point on the vertebral body to the most inferior-posterior point on the vertebral body. The VBHa was measured on the anterior surface of the vertebra from the most superior-anterior point on the vertebral body to the most inferior-anterior point on the vertebral body. The EPDu was measured on the superior surface of the vertebral body, from the most superior-anterior point to the most superior-posterior point. Finally the EPDl was measured on the inferior surface of the vertebral body, from the most inferior-anterior point to the most inferior-posterior point.

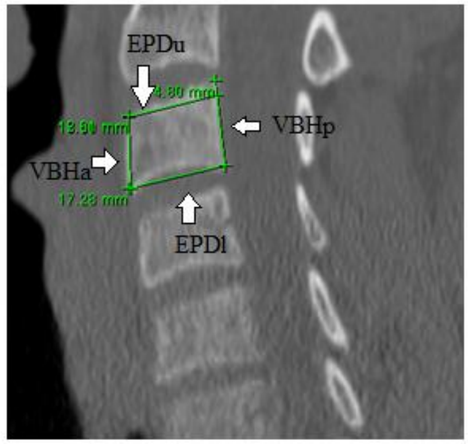


Figure 11: Sagittal Measurements

The axial view was more complicated since the alignment of the slice was not perfectly aligned, as can be seen in Figure 12. In these slices a coordinate system had to be created to make sure the most accurate measurement was taken. The X-axis was created utilizing the transverse process as markers, then using that axis the Y-axis was created 90° from it. With the axes created the SCW, SCD, and TPW were measured. The SCW was measured from the farthest point of one side of the spinal canal to the other along the X-axis. The SCD was measured from the farthest anterior point of the spinal canal to the most posterior point of the spinal canal along the Y-axis that was created. Finally the TPW was measured from the farthest part of the transverse process to the other, again along the X-axis that was created.

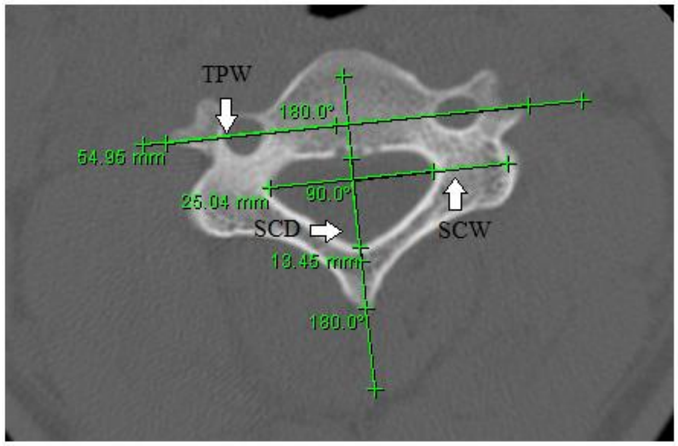


Figure 12: Axial Measurements

Statistical Analysis:

Statistical analysis was completed on two previous studies of different races, one utilizing the measurements completed by Tan on Chinese Singaporeans, and another utilizing measurements completed by Panjabi on Caucasians. The lack of information on the African American race did not allow for this investigation to be accomplished. An investigation of this type was accomplished for the measurements completed by the author, with further investigation into differences present in morphometry with respect to race, gender and age. The methods of how this was accomplished are discussed further in the following sections.

Previous Studies – Race**:**

Investigation into correlations present in the vertebrae of the cervical spine was completed for the Chinese Singaporean race (utilizing measurements completed by Tan) and the Caucasian race (utilizing measurements completed by Panjabi). In this analysis, a comparison of one vertebral body's measurements was compared. A good example is comparing data from the C3 vertebra to other C3 vertebral data. The statistical analysis was completed using linear regression, and ANOVA with the use of SAS® 9.2 TS Level 2M0 (Inc., SAS 9.2). A 95% confidence interval was used to test the significance between variables, thus a $P \leq 0.05$ found the two variables investigated to be statistically linearly correlated (Douglas C. Montgomery 2007). Significant correlation in this respect shows the interdependence between the two or more variables being compared (Douglas C. Montgomery 2007). This type of knowledge will help to model this section of the spine more accurately. Knowing how the endplate width decreases as the pedicle width increases can show how the morphometry of the cervical spine is all interdependent upon each other. It is not only of interest to see how if the endplate width increases the endplate area will also increase, but also to see the more anatomically irreconcilable relationships. This led to the investigation completed comparing all measurements within the vertebrae themselves. If there is a linear relationship explained between the anterior vertebral body height and the pedicle area on the left side this can assist in better modeling of the cervical spine vertebrae. With better spine modeling, device development can be improved because further knowledge can be known about the anatomy of this region.

It is important to find that the morphometry of the cervical spine was different with respect to race, gender, and age. If measurements were to find significantly different dimensions in these demographics, then it cannot be said that "one size fits all" for spinal devices. If spinal implants are being designed for a specific gender or race, i.e. 50% Caucasian male, the "one size fits all" mentality will not be of benefit for those that do not fit that range of dimensions. This investigation establishes the morphometric dimensions of the cervical spine.

There were a total of 600 comparisons completed for each vertebra (from C3-C7) in the Chinese Singaporean race, totaling 3000 comparisons for this particular race. As for the Caucasian race there were a total of 552 comparisons completed for each vertebral body segment, totaling 2760 comparisons for this particular race. Utilizing the mean and ±1 standard deviation from the studies completed by Tan and Panjabi, SAS® random number generation was used to create a normally distributed data set. From this random number generation, 100 observations were simulated in order to make the comparisons more robust.

Measurements:

The same comparisons completed for the Chinese Singaporeans and Caucasians was accomplished with the measurements completed in this investigation. This part of the investigation was completed using JMP 9 using again linear regression and a confidence interval of 95% with a $P \leq 0.05$ finding the corresponding anthropometrics to be statistically linearly correlated.

Along with this an investigation into the correlations present between gender, race and age group was completed. With race including Caucasian and African American, and age groups divided in 18-40, 41-60, and 61+. This analysis was as well completed utilizing JMP 9. For this part of the investigation ANOVA was used with a null hypothesis that the means were equal; this was accomplished in the same aspect for both races and age groups. A $P \leq 0.05$ would cause for rejection of the null hypothesis thus stating that the means were different (Glenn Gamst 2008). When there was significant difference found post-hoc analysis was completed, for gender and race (female/male, and African American/Caucasian) post-hoc analysis only includes looking at the mean values of the samples to see which is larger. For the case of the age group since there were three groups post-hoc analysis was completed using Tukey-Kramer's Honestly Significant Difference test to see which group was significantly different (Glenn Gamst 2008).

In addition to this a separation of gender was done of the sample to investigate the race difference within gender, again using ANOVA with a $P \leq 0.05$ stating there is significant difference between the means.

Moment of Inertia:

Finally an estimate for the moment of inertia of the vertebral body was of interest, in order to establish the effect of moments on the body as well as its resistance to rotation. In order to accomplish this, the vertebral body was estimated to be in the shape of an elliptical frustum (see Figure 13). An elliptical frustum is the shape of a truncated elliptical cone.

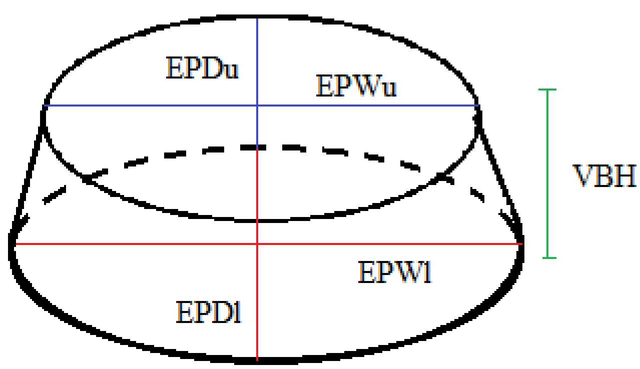


Figure 13: Vertebral body representation

The moment of inertia along the y, x and z axis of an elliptical thin plate (Figure 14) was found where:

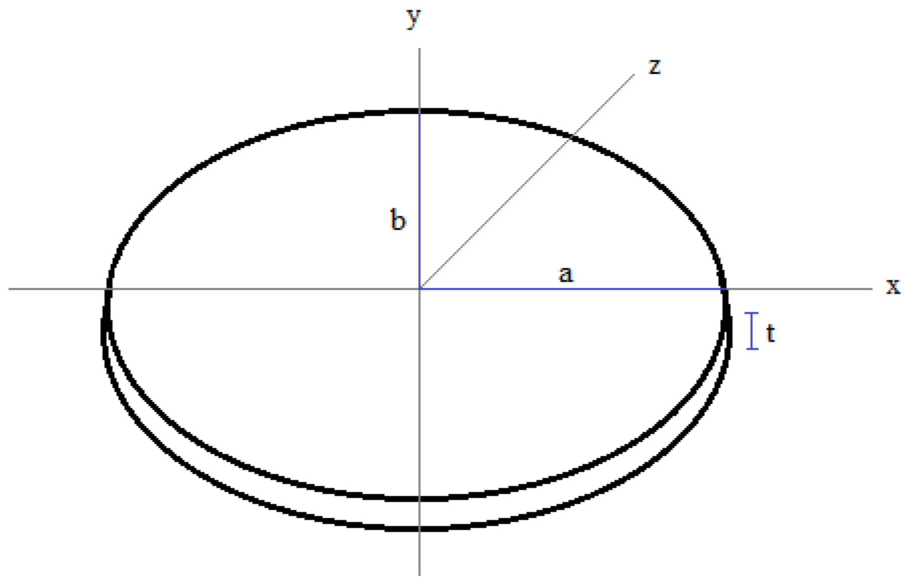


Figure 14: Elliptical Plate

a=long radius of the elliptical plate

b=short radius of the elliptical plate

t=thickness of the plate

m=mass of the plate

ρ=density of the plate

V=Volume of the plate

$$I_y = \rho t I_{y-ellipse} = \frac{1}{4}\rho\pi a^3 bt \qquad (1)$$

With $m = \rho V = \rho\pi abt$ thus leading: (2)

$$I_y = \frac{1}{4}\rho\pi a^3 bt = \frac{1}{4}ma^2 \qquad (3)$$

$$I_x = \rho t I_{x-ellipse} = \frac{1}{4}\rho\pi ab^3 t = \frac{1}{4}mb^2 \qquad (4)$$

$$I_z = I_x + I_y = \frac{1}{4}ma^2 + \frac{1}{4}mb^2 = \frac{1}{4}m\left(a^2 + b^2\right) \qquad (5)$$

Using the basis of this the moment of inertia of an elliptical cone can be found (see Figure 15).

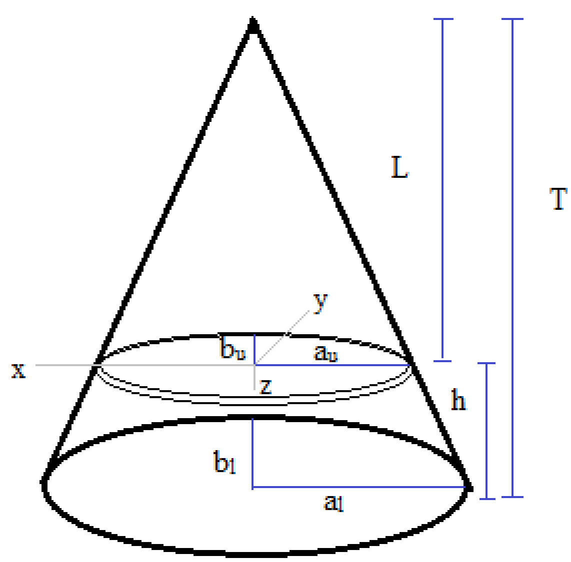


Figure 15: Elliptical Cone

Utilizing equation of an ellipse and the theory of similar triangles it can be stated that:

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = \frac{z^2}{T^2} \qquad (6)$$

$$\frac{a_l}{T} = \frac{a}{z} \qquad \frac{b_l}{T} = \frac{b}{z} \qquad (7)$$

Equation 2 can also be stated as, $dm = \rho\pi abdz$ (8)

Substituting in the values for a and b from equation 7 into equation 8 then results in:

$$dm = \rho\pi\left(\frac{a_l z}{T}\right)\left(\frac{b_l z}{T}\right)dz \qquad (9)$$

Using equation 5 the moment of inertia along the z-axis of the elliptical cone can be found as:

$$dI_z = \frac{1}{4}\left(a^2 + b^2\right)dm = \frac{1}{4}\left(\frac{a_l^2 z^2}{T^2} + \frac{b_;^2}{T^2}\right)\left(\rho\pi\frac{a_l z}{T}\frac{b_l z}{T}\right)dz = \frac{\rho\pi a_l b_l}{4T^2}\left(\frac{a_l^2}{T^2} + \frac{b_l^2}{T^2}\right)z^4 dz \qquad (10)$$

Integrating equation 10 results in:

$$I_z = \frac{\rho\pi a_l b_;}{4T^2}\left(\frac{a_l^2}{T^2} + \frac{b_l^2}{T^2}\right)\int_0^T z^4 dz = \frac{\rho\pi a_l b_;}{4T^2}\left(\frac{a_l^2}{T^2} + \frac{b_l^2}{T^2}\right)\frac{1}{5}T^5 = \frac{\rho\pi a_l b_l T^3}{20}\left(\frac{a_l^2}{T^2} + \frac{b_l^2}{T^2}\right) \qquad (11)$$

To find the moment of inertia of the frustum the top cone (with base a_u and b_u) will be subtracted from the larger cone (with base a_l and b_l). The moment of the inertia of the larger cone along the z-axis is the same as displayed in equation 11:

$$I_{Tz} = \frac{\rho\pi a_l b_l T^3}{20}\left(\frac{a_l^2}{T^2} + \frac{b_l^2}{T^2}\right) \qquad (12)$$

Using the corresponding radii, and heights the moment of inertia of the top cone along the z-axis is found using equation 11:

$$I_{2z} = \frac{\rho\pi a_u b_u L^3}{20}\left(\frac{a_u^2}{L^2} + \frac{b_u^2}{L^2}\right) \qquad (13)$$

Finally to find the moment of inertia of the frustum along the z-axis:

$$I_z = I_{Tz} - I_{2z} = \left[\frac{\rho\pi a_l b_l T^3}{20} \left(\frac{a_l^2}{T^2} + \frac{b_l^2}{T^2} \right) \right] - \left[\frac{\rho\pi a_u b_u L^3}{20} \left(\frac{a_u^2}{L^2} + \frac{b_u^2}{L^2} \right) \right] \quad (14)$$

Using the following two equations, substitutions for L and T can be made:

$$T - h = L \qquad \frac{a_u}{L} = \frac{a_l}{T} \quad (15)$$

$$\frac{a_u}{T-h} = \frac{a_l}{T} \Rightarrow T = \frac{a_l h}{a_l - a_u} \quad (16)$$

$$\frac{a_u}{L} = \frac{a_l}{L+h} \Rightarrow L = \frac{a_u h}{a_l - a_u} \quad (17)$$

Plugging the values of T and L from equations 16 and 17 into equations 12 and 13 results in:

$$I_{Tz} = \frac{\rho\pi a_l^4 b_l h^3}{20(a_l^3 - 3a_u a_l^2 - a_u^2 a_l - a_u^3)} \left(\frac{a_l^2 - 2a_u a_l + a_u^2}{h^2} + \frac{b_l^2 \left(a_l^2 - 2a_u a_l + a_u^2 \right)}{a_l^2 h^2} \right) \quad (18)$$

$$I_{2z} = \frac{\rho\pi a_u^4 b_{ul} h^3}{20(a_l^3 - 3a_u a_l^2 - a_u^2 a_l - a_u^3)} \left(\frac{a_l^2 - 2a_u a_l + a_u^2}{h^2} + \frac{b_u^2 \left(a_l^2 - 2a_u a_l + a_u^2 \right)}{a_u^2 h^2} \right) \quad (19)$$

The final moment of inertia of the frustum along the z-axis was then solved in Matlab and found to be:

$$I_z = \frac{\rho\pi h \left(a_l^4 b_l + a_l^2 b_l^3 - a_u^4 b_u - a_u^2 b_u^3 \right)}{20(a_l - a_u)} \quad (20)$$

Using the following substitutions for measurements that are collected from this investigation results in:

$$a_u = \frac{EPWu}{2} \quad a_l = \frac{EPWl}{2} \quad b_u = \frac{EPDu}{2} \quad b_l = \frac{EPDl}{2} \quad h = VBH \quad (21)$$

$$I_z = \frac{\rho\pi(VBH)\left(EPDl^3 EPWl^2 + EPDl \cdot EPWl^4 - EPDu^3 EPWu^2 - EPDu \cdot EPWu^4 \right)}{320\left(EPWl - EPWu \right)} \quad (22)$$

RESULTS

Previous Studies – Race:

A simple linear regression analysis was used with the morphometric analysis data of Tan and Panjabi. Random data fitting to mean and ± 1 standard deviation were generated using SAS. Normal distribution was assumed to describe the data, (100 data points). Analysis revealed a total of 128 significant correlations from C3-C7 in the Chinese Singaporean population, with 27 being in the C3 vertebra, 28 in the C4 vertebra, 25 in the C5 vertebra, 28 in the C6 vertebra, and 20 in the C7 vertebra (these results are displayed in Table 9). There were a similar amount of correlations found in the Caucasian population with a total of 133, with 35 being in the C3 vertebra, 26 in the C4 vertebra, 28 in the C5 vertebra, 18 in the C6 vertebra, and 26 in the C7 vertebra (also displayed in Table 10). The table displays the slope (m), y-intercept (b), and the Probability greater than F (P>F), where the equation of the linear relationship found is described by y=mx+b.

Table 9: Chinese Singaporean Correlations part 1

<table>
<tr><th rowspan="2"></th><th colspan="3">C3</th><th colspan="3">C4</th><th colspan="3">C5</th><th colspan="3">C6</th><th colspan="3">C7</th></tr>
<tr><th>m</th><th>b</th><th>P>F</th><th>m</th><th>b</th><th>P>F</th><th>m</th><th>b</th><th>P>F</th><th>m</th><th>b</th><th>P>F</th><th>m</th><th>b</th><th>P>F</th></tr>
<tr><td>EPAl vs EPWu</td><td colspan="3">Not Significant</td><td colspan="3" rowspan="3">Not Significant</td><td>-27.65</td><td>698.89</td><td>0.01</td><td colspan="3" rowspan="2">Not Significant</td><td colspan="3" rowspan="11">Not Significant</td></tr>
<tr><td>EPAl vs EPDu</td><td>-27.43</td><td>590.44</td><td>0.01</td><td colspan="3" rowspan="6">Not Significant</td></tr>
<tr><td>EPAl vs EPDl</td><td>-9.81</td><td>365.04</td><td>0.04</td><td>6.19</td><td>218.46</td><td>0.01</td></tr>
<tr><td>EPAl vs SCW</td><td colspan="3" rowspan="2">Not Significant</td><td>-4.82</td><td>332.09</td><td>0.04</td><td colspan="3" rowspan="10">Not Significant</td></tr>
<tr><td>EPAl vs SCD</td><td>-8.57</td><td>327.61</td><td>0.02</td></tr>
<tr><td>EPAl vs PDAr</td><td>3.98</td><td>148.93</td><td>0.00</td><td colspan="3">Not Significant</td></tr>
<tr><td>EPAl vs PDIsr</td><td colspan="3" rowspan="6">Not Significant</td><td>-2.64</td><td>344.25</td><td>0.01</td></tr>
<tr><td>EPAu vs VBHp</td><td colspan="3" rowspan="3">Not Significant</td><td>16.66</td><td>1.72</td><td>0.03</td></tr>
<tr><td>EPAu vs SCA</td><td>0.21</td><td>154.56</td><td>0.03</td></tr>
<tr><td>EPAu vs PDWl</td><td>-20.59</td><td>286.93</td><td>0.01</td></tr>
<tr><td>EPAu vs PDWr</td><td>-5.21</td><td>192.94</td><td>0.01</td><td colspan="3" rowspan="9">Not Significant</td></tr>
<tr><td>EPAu vs PDIsr</td><td colspan="3" rowspan="10">Not Significant</td><td>1.91</td><td>163.74</td><td>0.03</td></tr>
<tr><td>EPDl vs SCD</td><td>-0.15</td><td>16.68</td><td>0.03</td><td colspan="3" rowspan="2">Not Significant</td></tr>
<tr><td>EPDl vs TPW</td><td colspan="3" rowspan="2">Not Significant</td><td>0.08</td><td>11.51</td><td>0.02</td></tr>
<tr><td>EPDl vs PDWl</td><td colspan="3">Not Significant</td><td>0.36</td><td>13.53</td><td>0.01</td></tr>
<tr><td>EPDl vs EPAl</td><td>0.00</td><td>16.05</td><td>0.04</td><td>0.02</td><td>12.17</td><td>0.01</td><td colspan="3" rowspan="5">Not Significant</td></tr>
<tr><td>EPDl vs PDItr</td><td colspan="3" rowspan="6">Not Significant</td><td>-0.06</td><td>15.96</td><td>0.02</td></tr>
<tr><td>EPDu vs EPWl</td><td>-0.25</td><td>19.60</td><td>0.01</td></tr>
<tr><td>EPDu vs EPDl</td><td>-0.17</td><td>17.35</td><td>0.00</td></tr>
<tr><td>EPDu vs VBHa</td><td>0.13</td><td>13.04</td><td>0.03</td><td colspan="3" rowspan="5">Not Significant</td></tr>
<tr><td>EPDu vs TPW</td><td colspan="3" rowspan="4">Not Significant</td><td>0.06</td><td>11.93</td><td>0.00</td></tr>
<tr><td>EPDu vs PDHr</td><td>0.02</td><td>13.14</td><td>0.12</td><td colspan="3" rowspan="2">Not Significant</td></tr>
<tr><td>EPDu vs EPAl</td><td>0.00</td><td>14.12</td><td>0.01</td><td colspan="3" rowspan="2">Not Significant</td></tr>
<tr><td>EPDu vs PDAr</td><td colspan="3">Not Significant</td><td>-0.03</td><td>15.90</td><td>0.04</td></tr>
</table>

Table 9: Chinese Singaporean Correlations continued part 2

	C3			C4			C5			C6			C7		
	m	b	P>F	m	b	P>F	m	b	P>F	m	b	P>F	m	b	P>F
EPDu vs EPItl	0.00	13.62	0.01	0.03	13.87	0.02	Not Significant						-0.12	15.65	0.01
EPItl vs EPDu	-1.34	21.56	0.01	1.54	-18.16	0.02							0.01	14.32	-0.61
EPItl vs PDHl	Not Significant						0.18	1.47	0.04	Not Significant			Not Significant		
EPItl vs EPItu	-0.02	3.40	0.05												
EPItu vs SCW	Not Significant												0.35	0.16	0.05
EPItu vs SPL										-0.09	8.96	0.01	Not Significant		
EPItu vs TPW	1.27	-48.93	0.02				Not Significant								
EPItu vs PDWr	Not Significant			Not Significant						Not Significant			0.24	5.65	0.03
EPItu vs PDItr	-0.78	-1.21	0.03												
EPWl vs EPDu										-0.25	23.12	0.01			
EPWl vs PDHl										0.16	18.56	0.02			
EPWl vs SPL							-0.02	16.57	0.05						
EPWu vs SCW	Not Significant						0.05	13.82	0.03	Not Significant					
EPWu vs PDHl				-0.10	15.33	0.03	Not Significant								
EPWu vs PDWr							0.09	14.44	0.03				Not Significant		
EPWu vs SPL							Not Significant			0.00	15.80	0.04			
EPWu vs EPAl							0.00	15.52	0.01						
PDAl vs VBHa	-1.08	38.14	0.05							Not Significant					
PDAl vs PDWr	0.42	25.42	0.01	Not Significant											
PDAl vs TPW	Not Significant						Not Significant			0.36	12.00	0.03			
PDAl vs PDItl	-0.22	26.28	0.02												
PDAr vs EPDu	Not Significant									Not Significant			-1.56	55.73	0.04
PDAr vs VBHa	1.25	16.34	0.04										Not Significant		

Table 9: Chinese Singaporean Correlations continued part 3

<table>
<tr><th rowspan="2"></th><th colspan="3">C3</th><th colspan="3">C4</th><th colspan="3">C5</th><th colspan="3">C6</th><th colspan="3">C7</th></tr>
<tr><th>m</th><th>b</th><th>P>F</th><th>m</th><th>b</th><th>P>F</th><th>m</th><th>b</th><th>P>F</th><th>m</th><th>b</th><th>P>F</th><th>m</th><th>b</th><th>P>F</th></tr>
<tr><td>PDAr vs EPAl</td><td>0.03</td><td>21.46</td><td>0.00</td><td colspan="3">Not Significant</td><td colspan="3" rowspan="9">Not Significant</td><td colspan="3" rowspan="2">Not Significant</td><td colspan="3" rowspan="6">Not Significant</td></tr>
<tr><td>PDAr vs PDIsr</td><td colspan="3" rowspan="21">Not Significant</td><td>-0.14</td><td>36.77</td><td>0.05</td></tr>
<tr><td>PDAr s PDItl</td><td colspan="3" rowspan="2">Not Significant</td><td>0.22</td><td>32.48</td><td>0.05</td></tr>
<tr><td>PDAr vs PDItr</td><td>0.23</td><td>32.23</td><td>0.02</td></tr>
<tr><td>PDHl vs EPWl</td><td colspan="3">Not Significant</td><td>0.36</td><td>-1.14</td><td>0.02</td></tr>
<tr><td>PDHl vs EPWu</td><td>-0.46</td><td>13.30</td><td>0.03</td><td colspan="3" rowspan="5">Not Significant</td></tr>
<tr><td>PDHl vs PDWl</td><td colspan="3">Not Significant</td><td>-0.19</td><td>7.61</td><td>0.05</td></tr>
<tr><td>PDHl vs PDWr</td><td>-0.30</td><td>7.95</td><td>0.00</td><td colspan="3" rowspan="10">Not Significant</td></tr>
<tr><td>PDHl vs SCA</td><td>-0.01</td><td>7.48</td><td>0.03</td></tr>
<tr><td>PDHl vs EPItl</td><td colspan="3" rowspan="2">Not Significant</td><td>0.24</td><td>5.70</td><td>0.04</td></tr>
<tr><td>PDHl vs PDItr</td><td colspan="3" rowspan="13">Not Significant</td><td>-0.05</td><td>6.28</td><td>0.02</td></tr>
<tr><td>PDHr vs EPDu</td><td>0.47</td><td>0.19</td><td>0.02</td><td colspan="3" rowspan="3">Not Significant</td></tr>
<tr><td>PDHr vs VBHa</td><td>0.17</td><td>5.15</td><td>0.03</td></tr>
<tr><td>PDHr vs PDItl</td><td>0.07</td><td>7.00</td><td>0.02</td></tr>
<tr><td>PDHr vs PDIsr</td><td colspan="3">Not Significant</td><td>-0.01</td><td>6.44</td><td>0.02</td></tr>
<tr><td>PDIsl vs SPL</td><td>-0.72</td><td>-22.25</td><td>0.01</td><td colspan="3">Not Significant</td></tr>
<tr><td>PDIsl vs EPItu</td><td colspan="3" rowspan="3">Not Significant</td><td>0.60</td><td>-45.52</td><td>0.03</td></tr>
<tr><td>PDIsr vs SCD</td><td colspan="3">Not Significant</td><td>1.12</td><td>18.26</td><td>0.03</td></tr>
<tr><td>PDIsr vs PDHr</td><td>-4.51</td><td>64.91</td><td>0.02</td><td colspan="3" rowspan="2">Not Significant</td></tr>
<tr><td>PDIsr vs EPAl</td><td>-0.02</td><td>45.29</td><td>0.01</td><td colspan="3" rowspan="4">Not Significant</td></tr>
<tr><td>PDIsr vs EPAu</td><td colspan="3">Not Significant</td><td>0.03</td><td>24.91</td><td>0.03</td></tr>
<tr><td>PDIsr vs PDAr</td><td>-0.20</td><td>45.73</td><td>0.05</td><td colspan="3" rowspan="2">Not Significant</td></tr>
<tr><td>PDItl vs VBHa</td><td>-1.14</td><td>-16.18</td><td>0.04</td><td>0.79</td><td>-8.47</td><td>0.02</td></tr>
</table>

Table 9: Chinese Singaporean Correlations continued part 4

	C3			C4			C5			C6			C7		
	m	b	P>F	m	b	P>F	m	b	P>F	m	b	P>F	m	b	P>F
PDItl vs PDHr	Not Significant			-0.69	0.00	0.02	Not Significant			Not Significant			Not Significant		
PDItl vs PDWr				Not Significant											
PDItl vs TPW	-0.29	7.17	0.05												
PDItl vs PDAl	-0.23	1.43	0.02												
PDItl vs PDAr	Not Significant									0.17	-0.88	0.05			
PDItr vs EPDl										-0.93	20.52	0.02			
PDItr vs SCD							-1.15	16.69	0.00	Not Significant					
PDItr vs SCW							Not Significant						-0.42	11.47	0.01
PDItr vs PDHl										-1.02	12.11	0.02	Not Significant		
PDItr vs PDAr										0.25	-2.29	0.02			
PDItr vs EPItu	-0.06	-6.00	0.03							Not Significant					
PDWl vs EPDl	Not Significant												0.17	3.01	0.01
PDWl vs SCD							0.07	3.91	0.02				Not Significant		
PDWl vs PDHl							Not Significant						-0.21	6.95	0.05
PDWl vs EPAu							0.00	5.35	0.01				Not Significant		
PDWr vs EPWu							0.52	-2.88	0.03						
PDWr vs PDHl				-0.39	7.09	0.00	Not Significant								
PDWr vs EPAu				-0.01	7.02	0.01									
PDWr vs PDAl	-0.05	5.79	0.01	Not Significant											
PDWr vs EPItu	Not Significant												0.36	3.42	0.00
PDWr vs EPItl							-0.22	5.49	0.01				Not Significant		
PDWr vs PDItl				-0.08	4.25	0.02	Not Significant								
SCA vs PDHl				-8.19	212.95	0.03									

Table 9: Chinese Singaporean Correlations continued part 5

<table>
<tr><th rowspan="2"></th><th colspan="3">C3</th><th colspan="3">C4</th><th colspan="3">C5</th><th colspan="3">C6</th><th colspan="3">C7</th></tr>
<tr><th>m</th><th>b</th><th>P>F</th><th>m</th><th>b</th><th>P>F</th><th>m</th><th>b</th><th>P>F</th><th>m</th><th>b</th><th>P>F</th><th>m</th><th>b</th><th>P>F</th></tr>
<tr><td>SCA vs EPAu</td><td colspan="3" rowspan="2">Not Significant</td><td colspan="3" rowspan="3">Not Significant</td><td>0.21</td><td>126.23</td><td>0.03</td><td colspan="3" rowspan="9">Not Significant</td><td colspan="3" rowspan="5">Not Significant</td></tr>
<tr><td>SCA vs EPItu</td><td>3.93</td><td>142.44</td><td>0.04</td></tr>
<tr><td>SCD vs EPDl</td><td>-0.30</td><td>14.79</td><td>0.03</td><td colspan="3" rowspan="2">Not Significant</td></tr>
<tr><td>SCD vs EPAl</td><td colspan="3" rowspan="17">Not Significant</td><td>-0.01</td><td>11.98</td><td>0.02</td></tr>
<tr><td>SCD vs PDWl</td><td colspan="3" rowspan="6">Not Significant</td><td>0.71</td><td>7.07</td><td>0.02</td></tr>
<tr><td>SCD vs PDIsr</td><td colspan="3">Not Significant</td><td>0.04</td><td>9.69</td><td>0.03</td></tr>
<tr><td>SCD vs PDItr</td><td>-0.07</td><td>10.74</td><td>0.00</td><td colspan="3" rowspan="5">Not Significant</td></tr>
<tr><td>SCW vs EPWu</td><td>0.84</td><td>7.80</td><td>0.03</td></tr>
<tr><td>SCW vs VBHp</td><td>-0.94</td><td>30.99</td><td>0.02</td></tr>
<tr><td>SCW vs SPL</td><td colspan="3" rowspan="4">Not Significant</td><td>-0.07</td><td>23.45</td><td>0.00</td></tr>
<tr><td>SCW vs EPAl</td><td>-0.01</td><td>21.53</td><td>0.04</td><td colspan="3" rowspan="4">Not Significant</td></tr>
<tr><td>SCW vs EPItu</td><td colspan="3" rowspan="5">Not Significant</td><td>0.11</td><td>18.89</td><td>0.05</td></tr>
<tr><td>SCW vs PDItr</td><td>-0.14</td><td>20.12</td><td>0.01</td></tr>
<tr><td>SPL vs EPWl</td><td>-1.95</td><td>64.68</td><td>0.05</td><td colspan="3" rowspan="4">Not Significant</td></tr>
<tr><td>SPL vs SCW</td><td colspan="3" rowspan="8">Not Significant</td><td>-1.14</td><td>63.74</td><td>0.00</td></tr>
<tr><td>SPL vs EPItu</td><td>-0.71</td><td>44.15</td><td>0.01</td></tr>
<tr><td>SPL vs PDIsl</td><td>-0.09</td><td>26.37</td><td>0.01</td><td colspan="3" rowspan="2">Not Significant</td></tr>
<tr><td>TPW vs EPDu</td><td colspan="3" rowspan="6">Not Significant</td><td>1.37</td><td>33.01</td><td>0.00</td></tr>
<tr><td>TPW vs EPDl</td><td>0.62</td><td>38.76</td><td>0.02</td><td colspan="3" rowspan="5">Not Significant</td></tr>
<tr><td>TPW vs PDAl</td><td>0.12</td><td>44.85</td><td>0.03</td></tr>
<tr><td>TPW vs EPItu</td><td>0.04</td><td>41.31</td><td>0.02</td><td colspan="3" rowspan="3">Not Significant</td></tr>
<tr><td>TPW vs PDItl</td><td>-0.14</td><td>40.80</td><td>0.05</td></tr>
<tr><td>VBHa vs EPDu</td><td colspan="3">Not Significant</td><td>0.37</td><td>4.22</td><td>0.03</td></tr>
</table>

Table 9: Chinese Singaporean Correlations continued part 6

<table>
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<tr><td>VBHa vs PDHr</td><td colspan="3">Not Significant</td><td>0.27</td><td>7.98</td><td>0.03</td><td colspan="3" rowspan="4">Not Significant</td><td colspan="3" rowspan="6">Not Significant</td><td colspan="3" rowspan="6">Not Significant</td></tr>
<tr><td>VBHa vs PDAl</td><td>-0.04</td><td>10.98</td><td>0.05</td><td colspan="3" rowspan="5">Not Significant</td></tr>
<tr><td>VBHa vs PDAr</td><td>0.03</td><td>8.97</td><td>0.04</td></tr>
<tr><td>VBHa vs PDItl</td><td>0.04</td><td>10.15</td><td>0.04</td></tr>
<tr><td>VBHp vs SCW</td><td colspan="3" rowspan="2">Not Significant</td><td>-0.06</td><td>12.59</td><td>0.02</td></tr>
<tr><td>VBHp vs EPAu</td><td>0.00</td><td>10.75</td><td>0.03</td></tr>
</table>

Table 10: Caucasian Correlations, Cadaver part 1

<table>
<tr><th rowspan="2"></th><th colspan="3">C3</th><th colspan="3">C4</th><th colspan="3">C5</th><th colspan="3">C6</th><th colspan="3">C7</th></tr>
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<tr><td>EPAl vs SCD</td><td colspan="3" rowspan="4">Not Significant</td><td>5.89</td><td>93.84</td><td>0.00</td><td colspan="3" rowspan="3">Not Significant</td><td colspan="3" rowspan="4">Not Significant</td><td colspan="3">Not Significant</td></tr>
<tr><td>EPAl vs PDHl</td><td colspan="3" rowspan="11">Not Significant</td><td>9.36</td><td>206.82</td><td>0.04</td></tr>
<tr><td>EPAl vs EPAu</td><td>0.25</td><td>206.73</td><td>0.01</td></tr>
<tr><td>EPAl vs PDIsl</td><td>0.57</td><td>220.57</td><td>0.04</td><td colspan="3" rowspan="3">Not Significant</td></tr>
<tr><td>EPAu vs SPL</td><td>2.60</td><td>92.58</td><td>0.02</td><td colspan="3">Not Significant</td><td>-0.84</td><td>251.72</td><td>0.03</td></tr>
<tr><td>EPAu vs PDHl</td><td colspan="3" rowspan="2">Not Significant</td><td>-4.55</td><td>216.47</td><td>0.02</td><td colspan="3" rowspan="14">Not Significant</td></tr>
<tr><td>EPAu vs EPAl</td><td colspan="3" rowspan="3">Not Significant</td><td>0.30</td><td>195.94</td><td>0.01</td></tr>
<tr><td>EPAu vs EPItu</td><td>-3.02</td><td>178.40</td><td>0.02</td><td colspan="3" rowspan="3">Not Significant</td></tr>
<tr><td>EPAu vs PDItl</td><td>-3.05</td><td>148.05</td><td>0.03</td></tr>
<tr><td>EPDl vs EPWu</td><td colspan="3" rowspan="2">Not Significant</td><td>0.22</td><td>14.02</td><td>0.04</td></tr>
<tr><td>EPDl vs SCW</td><td colspan="3" rowspan="7">Not Significant</td><td>-0.07</td><td>18.62</td><td>0.05</td></tr>
<tr><td>EPDl vs PDHl</td><td>0.25</td><td>13.70</td><td>0.03</td><td colspan="3" rowspan="8">Not Significant</td></tr>
<tr><td>EPDu vs EPWl</td><td colspan="3" rowspan="2">Not Significant</td><td>0.29</td><td>10.30</td><td>0.03</td></tr>
<tr><td>EPDu vs VBHp</td><td>-0.30</td><td>18.64</td><td>0.05</td></tr>
<tr><td>EPDu vs PDHr</td><td>-0.24</td><td>16.91</td><td>0.02</td><td colspan="3">Not Significant</td></tr>
<tr><td>EPDu vs PDAl</td><td colspan="3" rowspan="3">Not Significant</td><td>-0.06</td><td>16.77</td><td>0.01</td></tr>
<tr><td>EPItl vs SCW</td><td>0.20</td><td>-2.90</td><td>0.02</td></tr>
<tr><td>EPItl vs PDHr</td><td colspan="3" rowspan="7">Not Significant</td><td>-0.61</td><td>6.65</td><td>0.02</td></tr>
<tr><td>EPItl vs PDWr</td><td>-0.30</td><td>5.60</td><td>0.03</td><td colspan="3" rowspan="6">Not Significant</td></tr>
<tr><td>EPItl vs SCA</td><td colspan="3" rowspan="2">Not Significant</td><td>-0.01</td><td>4.81</td><td>0.00</td><td>0.00</td><td>1.00</td><td>0.01</td></tr>
<tr><td>EPItl vs PDAr</td><td colspan="3" rowspan="4">Not Significant</td><td>-0.03</td><td>2.65</td><td>0.03</td></tr>
<tr><td>EPItu vs EPWl</td><td>-0.57</td><td>12.73</td><td>0.01</td><td colspan="3" rowspan="3">Not Significant</td></tr>
<tr><td>EPItu vs PDHl</td><td>0.44</td><td>-0.18</td><td>0.03</td></tr>
<tr><td>EPItu vs EPAu</td><td>-0.02</td><td>6.19</td><td>0.02</td></tr>
</table>

Table 10: Caucasian Correlations, Cadaver part 2

<table>
<tr><th rowspan="2"></th><th colspan="3">C3</th><th colspan="3">C4</th><th colspan="3">C5</th><th colspan="3">C6</th><th colspan="3">C7</th></tr>
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<tr><td>EPWl vs EPWu</td><td colspan="3" rowspan="3">Not Significant</td><td colspan="3">Not Significant</td><td>0.12</td><td>17.17</td><td>0.05</td><td colspan="3" rowspan="5">Not Significant</td><td colspan="3" rowspan="12">Not Significant</td></tr>
<tr><td>EPWl vs EPDu</td><td>0.17</td><td>14.41</td><td>0.03</td><td colspan="3" rowspan="8">Not Significant</td></tr>
<tr><td>EPWl vs SPL</td><td>0.10</td><td>14.09</td><td>0.03</td></tr>
<tr><td>EPWl vs PDWr</td><td>-0.14</td><td>18.08</td><td>0.00</td><td colspan="3" rowspan="4">Not Significant</td></tr>
<tr><td>EPWl vs EPItu</td><td>-0.11</td><td>17.60</td><td>0.01</td></tr>
<tr><td>EPWu vs SCD</td><td colspan="3">Not Significant</td><td>-0.21</td><td>22.32</td><td>0.04</td></tr>
<tr><td>EPWu vs PDIsr</td><td>-0.07</td><td>19.02</td><td>0.02</td><td colspan="3" rowspan="2">Not Significant</td></tr>
<tr><td>PDAl vs EPDu</td><td colspan="3">Not Significant</td><td>-1.26</td><td>44.30</td><td>0.01</td></tr>
<tr><td>PDAl vs VBHp</td><td>-1.39</td><td>37.17</td><td>0.01</td><td>1.37</td><td>9.39</td><td>0.04</td><td>1.77</td><td>9.21</td><td>0.04</td></tr>
<tr><td>PDAl vs PDWl</td><td colspan="3">Not Significant</td><td colspan="3" rowspan="11">Not Significant</td><td>1.74</td><td>15.65</td><td>0.01</td><td colspan="3" rowspan="8">Not Significant</td></tr>
<tr><td>PDAl vs PDWr</td><td>0.73</td><td>16.87</td><td>0.04</td><td colspan="3">Not Significant</td></tr>
<tr><td>PDAl vs SCA</td><td colspan="3" rowspan="5">Not Significant</td><td>0.01</td><td>20.75</td><td>0.04</td></tr>
<tr><td>PDAl vs PDItr</td><td colspan="3">Not Significant</td><td>0.03</td><td>23.34</td><td>0.34</td></tr>
<tr><td>PDAr vs SCW</td><td>-0.52</td><td>35.91</td><td>0.03</td><td colspan="3">Not Significant</td></tr>
<tr><td>PDAr vs EPItl</td><td colspan="3" rowspan="3">Not Significant</td><td>-1.60</td><td>33.85</td><td>0.03</td></tr>
<tr><td>PDAr vs PDItl</td><td>0.52</td><td>26.11</td><td>0.02</td></tr>
<tr><td>PDHl vs EPDl</td><td>0.18</td><td>4.25</td><td>0.03</td><td colspan="3" rowspan="3">Not Significant</td></tr>
<tr><td>PDHl vs PDWr</td><td colspan="3" rowspan="4">Not Significant</td><td>0.23</td><td>6.04</td><td>0.01</td><td>0.17</td><td>6.37</td><td>0.01</td></tr>
<tr><td>PDHl vs EPAu</td><td>-0.01</td><td>9.74</td><td>0.02</td><td colspan="3" rowspan="5">Not Significant</td></tr>
<tr><td>PDHl vs EPAl</td><td colspan="3" rowspan="4">Not Significant</td><td>0.00</td><td>6.21</td><td>0.04</td></tr>
<tr><td>PDHl vs SCA</td><td>0.00</td><td>8.14</td><td>0.04</td><td colspan="3" rowspan="3">Not Significant</td></tr>
<tr><td>PDHl vs EPItu</td><td>0.11</td><td>6.75</td><td>0.03</td><td colspan="3" rowspan="2">Not Significant</td></tr>
<tr><td>PDHl vs PDIsr</td><td>0.06</td><td>4.67</td><td>0.05</td></tr>
</table>

Table 10: Caucasian Correlations, Cadaver part 3

	C3			C4			C5			C6			C7		
	m	b	P>F	m	b	P>F	m	b	P>F	m	b	P>F	m	b	P>F
PDHr vs EPDu	-0.23	10.97	0.02	Not Significant			Not Significant			Not Significant			Not Significant		
PDHr vs PDWl	Not Significant						0.30	5.22	0.03						
PDHr vs SPL				0.13	3.41	0.00	Not Significant								
PDHr vs SCA				Not Significant			0.00	7.48	0.05						
PDHr vs PDIsl				-0.04	9.13	0.02	Not Significant								
PDHr vs PDIsr				-0.06	9.86	0.03									
PDIsl vs VBHp				Not Significant			-3.22	77.50	0.01						
PDIsl vs SCD							Not Significant			0.91	17.35	0.03			
PDIsl vs PDHr				-1.27	53.70	0.02				Not Significant					
PDIsl vs EPAl				Not Significant			0.08	22.53	0.04						
PDIsr vs EPWu	-0.69	52.55	0.02				Not Significant								
PDIsr vs VBHp	Not Significant									2.49	2.85	0.00			
PDIsr vs SCW										Not Significant			0.54	20.00	0.05
PDIsr vs PDHl	0.69	36.65	0.05										Not Significant		
PDIsr vs PDHr	Not Significant			-0.86	51.42	0.03									
PDIsr vs EPItl	-0.38	43.06	0.01	Not Significant											
PDIsr vs PDItl	Not Significant												0.44	28.96	0.00
PDIsr vs PDItr				0.19	46.69	0.02							0.27	29.60	0.05
PDItl vs EPWl				Not Significant			-0.99	13.47	0.02				Not Significant		
PDItl vs PDWr							Not Significant						0.79	3.74	0.02
PDItl vs SPL										0.35	-6.15	0.01	Not Significant		
PDItl vs EPAu	-0.01	-4.53	0.03							Not Significant					
PDItl vs PDAr	Not Significant												0.11	6.07	0.02
PDItl vs PDIsr													0.21	2.76	0.00

Table 10: Caucasian Correlations, Cadaver part 4

<table>
<tr><th rowspan="2"></th><th colspan="3">C3</th><th colspan="3">C4</th><th colspan="3">C5</th><th colspan="3">C6</th><th colspan="3">C7</th></tr>
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<tr><td>PDItr vs PDAl</td><td colspan="3">Not Significant</td><td colspan="3" rowspan="3">Not Significant</td><td colspan="3" rowspan="5">Not Significant</td><td colspan="3" rowspan="4">Not Significant</td><td>0.14</td><td>9.52</td><td>0.03</td></tr>
<tr><td>PDItr vs SPL</td><td>1.48</td><td>-53.11</td><td><0.0001</td><td colspan="3" rowspan="2">Not Significant</td></tr>
<tr><td>PDItr vs SCA</td><td>0.02</td><td>-13.41</td><td>0.03</td></tr>
<tr><td>PDItr vs PDIsr</td><td colspan="3" rowspan="4">Not Significant</td><td>0.27</td><td>-20.20</td><td>0.02</td><td>0.15</td><td>8.64</td><td>0.05</td></tr>
<tr><td>PDWl vs VBHp</td><td>-0.21</td><td>7.45</td><td>0.04</td><td>0.36</td><td>1.77</td><td>0.02</td><td colspan="3" rowspan="9">Not Significant</td></tr>
<tr><td>PDWl vs PDHr</td><td colspan="3" rowspan="9">Not Significant</td><td>0.15</td><td>4.10</td><td>0.03</td><td colspan="3" rowspan="3">Not Significant</td></tr>
<tr><td>PDWl vs PDAl</td><td>0.03</td><td>4.28</td><td>0.01</td></tr>
<tr><td>PDWr vs EPWl</td><td>-0.56</td><td>15.36</td><td>0.00</td><td>0.31</td><td>-0.02</td><td>0.01</td></tr>
<tr><td>PDWr vs PDHl</td><td colspan="3">Not Significant</td><td>0.26</td><td>4.07</td><td>0.01</td><td>0.42</td><td>3.19</td><td>0.01</td></tr>
<tr><td>PDWr vs TPW</td><td>-0.08</td><td>9.84</td><td>0.03</td><td>-0.03</td><td>7.54</td><td>0.04</td><td colspan="3" rowspan="9">Not Significant</td></tr>
<tr><td>PDWr vs SCA</td><td colspan="3">Not Significant</td><td>0.00</td><td>6.64</td><td>0.05</td></tr>
<tr><td>PDWr vs PDAl</td><td>0.06</td><td>4.36</td><td>0.04</td><td colspan="3" rowspan="4">Not Significant</td></tr>
<tr><td>PDWr vs EPItl</td><td>-0.03</td><td>5.72</td><td>0.03</td></tr>
<tr><td>PDWr vs PDItl</td><td colspan="3" rowspan="6">Not Significant</td><td>0.07</td><td>6.01</td><td>0.02</td></tr>
<tr><td>SCA vs PDHl</td><td>-13.79</td><td>380.53</td><td>0.04</td><td colspan="3" rowspan="4">Not Significant</td></tr>
<tr><td>SCA vs PDHr</td><td colspan="3" rowspan="8">Not Significant</td><td>-13.95</td><td>349.08</td><td>0.05</td></tr>
<tr><td>SCA vs PDWr</td><td>-15.69</td><td>349.14</td><td>0.05</td></tr>
<tr><td>SCA vs PDAl</td><td>2.79</td><td>186.49</td><td>0.04</td></tr>
<tr><td>SCA vs EPItl</td><td colspan="3" rowspan="5">Not Significant</td><td>-10.22</td><td>288.56</td><td>0.00</td><td>18.43</td><td>188.69</td><td>0.01</td></tr>
<tr><td>SCA vs PDItr</td><td>2.89</td><td>274.35</td><td>0.03</td><td colspan="3">Not Significant</td><td colspan="3" rowspan="3">Not Significant</td></tr>
<tr><td>SCD vs EPWu</td><td colspan="3">Not Significant</td><td>-0.20</td><td>21.83</td><td>0.04</td></tr>
<tr><td>SCD vs SPL</td><td>0.38</td><td>5.00</td><td>0.02</td><td colspan="3" rowspan="2">Not Significant</td></tr>
<tr><td>SCD vs TPW</td><td colspan="3">Not Significant</td><td>5.84</td><td>27.09</td><td>0.04</td></tr>
</table>

Table 10: Caucasian Correlations, Cadaver part 5

<table>
<tr><th rowspan="2"></th><th colspan="3">C3</th><th colspan="3">C4</th><th colspan="3">C5</th><th colspan="3">C6</th><th colspan="3">C7</th></tr>
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<tr><td>SCD vs EPAl</td><td colspan="3" rowspan="7">Not Significant</td><td>0.02</td><td>13.84</td><td>0.00</td><td colspan="3" rowspan="3">Not Significant</td><td colspan="3">Not Significant</td><td colspan="3" rowspan="2">Not Significant</td></tr>
<tr><td>SCD vs PDIsl</td><td colspan="3" rowspan="4">Not Significant</td><td>0.05</td><td>16.40</td><td>0.03</td></tr>
<tr><td>SCW vs EPDl</td><td colspan="3" rowspan="7">Not Significant</td><td>-0.53</td><td>33.23</td><td>0.05</td></tr>
<tr><td>SCW vs PDAr</td><td>-0.09</td><td>27.13</td><td>0.03</td><td colspan="3">Not Significant</td></tr>
<tr><td>SCW vs PDIsr</td><td colspan="3" rowspan="10">Not Significant</td><td>0.07</td><td>21.88</td><td>0.05</td></tr>
<tr><td>SCW vs EPItl</td><td>0.29</td><td>24.06</td><td>0.02</td><td colspan="3" rowspan="7">Not Significant</td></tr>
<tr><td>SPL vs EPWl</td><td>0.49</td><td>21.91</td><td>0.03</td></tr>
<tr><td>SPL vs SCD</td><td>0.15</td><td>27.22</td><td>0.02</td><td colspan="3">Not Significant</td></tr>
<tr><td>SPL vs PDHr</td><td colspan="3">Not Significant</td><td>0.69</td><td>25.08</td><td>0.00</td></tr>
<tr><td>SPL vs EPAu</td><td>0.02</td><td>26.30</td><td>0.02</td><td colspan="3" rowspan="7">Not Significant</td><td>-0.06</td><td>47.08</td><td>0.03</td></tr>
<tr><td>SPL vs PDItl</td><td colspan="3">Not Significant</td><td>0.19</td><td>33.31</td><td>0.01</td></tr>
<tr><td>SPL vs PDItr</td><td>0.12</td><td>30.68</td><td><0.0001</td><td colspan="3" rowspan="6">Not Significant</td></tr>
<tr><td>TPW vs VBHp</td><td colspan="3" rowspan="2">Not Significant</td><td>-0.65</td><td>74.93</td><td>0.01</td></tr>
<tr><td>TPW vs SCD</td><td>-0.23</td><td>70.08</td><td>0.04</td></tr>
<tr><td>TPW vs PDWr</td><td>-0.56</td><td>53.20</td><td>0.03</td><td>-1.28</td><td>54.40</td><td>0.04</td><td colspan="3" rowspan="4">Not Significant</td></tr>
<tr><td>VBHp vs EPWl</td><td colspan="3" rowspan="4">Not Significant</td><td>-0.23</td><td>15.88</td><td>0.01</td></tr>
<tr><td>VBHp vs EPDu</td><td>-0.13</td><td>13.47</td><td>0.05</td><td colspan="3" rowspan="4">Not Significant</td></tr>
<tr><td>VBHp vs PDWl</td><td>-0.20</td><td>12.43</td><td>0.04</td><td>0.16</td><td>10.04</td><td>0.02</td></tr>
<tr><td>VBHp vs TPW</td><td colspan="3">Not Significant</td><td colspan="3">Not Significant</td><td>-0.09</td><td>18.88</td><td>0.01</td></tr>
<tr><td>VBHp vs PDAl</td><td>-0.04</td><td>12.57</td><td>0.01</td><td>0.03</td><td>10.67</td><td>0.04</td><td>0.02</td><td>10.27</td><td>0.04</td><td colspan="3" rowspan="3">Not Significant</td></tr>
<tr><td>VBHp vs PDIsl</td><td colspan="3" rowspan="2">Not Significant</td><td colspan="3" rowspan="2">Not Significant</td><td>-0.02</td><td>12.16</td><td>0.01</td><td colspan="3">Not Significant</td></tr>
<tr><td>VBHp vs PDIsr</td><td colspan="3">Not Significant</td><td>0.04</td><td>9.82</td><td>0.00</td></tr>
</table>

New Measurements:

New linear measurements were completed as described in the Methods section. These measurements were completed on 50 randomly selected subjects that consisted of both genders, and of both African American and Caucasian race. Of this sample 27 of them were male, with 25 being Caucasian and 2 African American. The female portion of the sample included 12 Caucasian and 5 African American female subjects, totaling to 17. The age of the subjects ranged from 18-91, dividing these subjects into 3 groups resulted in: 15 in the 18-40 age group, 12 in the 41-60 age group, and 17 in the 61+ age group. The summary of the measurements performed are displayed in Tables 11-13 with separation of gender, race, and age.

Table 11: CT measurements, Caucasian

Male Caucasian (mm)					
	C3	C4	C5	C6	C7
EPWu	16.1785	16.8349	17.5754	19.0494	21.6261
EPWl	18.8137	19.3526	20.1653	22.7662	26.0938
EPDu	15.7341	16.1706	16.6211	18.2023	18.9238
EPDl	16.9333	17.0973	18.6211	19.0675	18.1679
VBHp	15.3315	14.3733	14.1178	13.5255	14.8627
VBHa	14.2015	13.268	12.3699	12.4484	14.2311
SCW	25.1322	25.1629	26.1433	26.7853	26.7476
SCD	18.7258	15.0967	14.9516	15.5994	15.7622
TPW	53.3635	54.6664	55.0069	57.2746	61.0433
Female Caucasian (mm)					
	C3	C4	C5	C6	C7
EPWu	15.3655	16.0702	16.1451	17.7849	19.5365
EPWl	17.3708	17.5935	18.0625	20.6298	24.1058
EPDu	14.5784	14.4125	14.8894	16.4618	16.9314
EPDl	15.1173	15.4395	16.8605	16.9573	16.0771
VBHp	13.7192	13.2052	12.635	12.5617	14.514
VBHa	12.5395	12.0491	11.2169	11.3802	13.2547
SCW	24.1943	24.12	25.3307	28.2539	25.6148
SCD	18.1364	14.5147	14.6608	15.0689	15.2947
TPW	49.0469	50.735	52.1951	55.1931	58.4885

Table 12: CT Measurements, African American

Male African American (mm)					
	C3	C4	C5	C6	C7
EPWu	16.0584	17.2234	17.235	19.695	21.325
EPWl	19.3384	20.9034	22.0942	21.4684	23.2667
EPDu	16.5797	16.9057	17.253	17.7024	19.3004
EPDl	18.964	17.8894	19.519	20.3947	19.3344
VBHp	14.8647	13.6384	13.727	14.6534	14.1417
VBHa	14.011	13.737	12.4967	10.5227	12.916
SCW	24.0475	25.2267	25.1809	26.2834	26.5184
SCD	15.5225	13.6267	14.0292	14.395	13.8525
TPW	54.795	54.4384	57.8984	55.4834	61.2967
Female African American (mm)					
	C3	C4	C5	C6	C7
EPWu	14.9175	14.6436	15.6985	16.5967	19.1097
EPWl	15.3409	16.7134	17.3487	19.0268	22.0673
EPDu	14.2188	14.547	14.4402	14.939	14.8353
EPDl	15.2972	15.3115	16.0435	15.5201	15.0942
VBHp	13.3333	12.0935	12.0801	11.6902	13.218
VBHa	12.5094	11.1362	11.0362	10.8686	12.72
SCW	22.8975	23.4167	24.5133	24.7533	24.4675
SCD	16.1538	13.1954	13.6083	13.7034	13.4592
TPW	44.5479	46.875	48.1086	49.8436	54.3365

The analysis of race, and gender resulted in no significant difference between races but a significant difference in gender in most cases. Within the female gender there were generally no significant differences between race except for in the cases of: EPWl in the C3 vertebra, EPWl in the C4 vertebra, VBHp in the C4 vertebra, TPW in the C5 vertebra, SCD in the C6 vertebra, and SCD in the C7 vertebra with Caucasian being larger in all. In regards to gender it was found that there were significant differences, with male being larger than female except for the cases of: SCD in all 5 vertebral levels, SCW in the C6 vertebra, and VBHp in the C7 vertebra. The investigation into the similarities in age resulted in there being differences based on vertebral level and measurement, the results are tabulated in Table 13. If there was a significant difference in age, it was generally found that there was no difference in the 41-60 age group when compared to the 61+ group but different from the 18-40 group which had no difference to the 61+ age group. The 18-40 age group was found to be significantly smaller than the others in the following cases: EPWu in the C3 vertebra, EPDl in the C4 vertebra, EPDu/l in the C5 vertebra, EPWu/l in C6, and EPDl in the C6 vertebra. There was significant difference between the 18-40 age group and the 61+ group, but otherwise correlated in the following cases: EPDu in C6, and EPDu in C7.

Table 13: CT measurements, age

		EPWu	EPWl	EPDu	EPDl	VBHp	VBHa	SCW	SCD	TPW
C3	18-40	14.9206	16.9811	14.2744	15.166	14.4849	13.3457	24.4966	18.3624	51.1386
	40-60	16.4616	18.7755	16.0342	17.7897	14.8196	13.832	24.4719	18.0172	52.2096
	60+	16.1297	18.4796	15.6482	16.364	14.6591	13.5241	24.8256	18.1124	51.0523
	Diff	Yes	Yes	Yes	Yes	No	No	No	No	No
C4	18-40	15.6813	17.6267	14.6203	15.1961	13.4573	12.8169	24.4707	14.8064	52.7977
	40-60	16.8913	19.702	16.3344	17.4535	14.1764	13.0272	24.4044	14.3625	53.4921
	60+	16.6745	18.7932	15.7908	16.9211	13.739	12.4037	25.17	14.824	52.3742
	Diff	Yes	Yes	Yes	Yes	No	No	No	No	No
C5	18-40	15.9702	18.1023	14.7365	16.0363	13.0812	11.9133	25.6003	15.0444	53.9036
	40-60	17.9384	20.494	16.6396	19.644	14.1081	12.063	25.6344	14.1588	53.9814
	60+	17.1339	19.6677	16.4814	18.2845	13.3473	11.7982	25.8967	14.7901	53.3384
	Diff	Yes	Yes	Yes	Yes	No	No	No	No	No
C6	18-40	17.2518	20.1479	15.9805	16.5009	12.8846	11.8196	26.1702	15.6947	55.0786
	40-60	19.1242	22.5075	17.9917	19.2112	13.4911	11.9222	26.429	14.3974	56.2079
	60+	19.0448	22.4986	18.0642	18.854	13.0279	11.9294	28.1598	15.3892	56.4905
	Diff	Yes	Yes	Yes	Yes	No	No	No	No	No
C7	18-40	19.4647	23.5492	16.4192	16.2162	14.467	13.6689	25.709	14.9094	58.8499
	40-60	21.9515	26.0956	18.572	17.799	14.6644	13.8522	26.6745	14.7576	59.0076
	60+	21.053	25.4175	18.8175	17.9077	14.537	13.7063	26.2321	16.0264	60.6458
	Diff	Yes	No	Yes	No	No	No	No	No	No

Given that there were significant differences due to gender rather than race, the vertebral analysis (similar to what was completed for the Chinese Singaporean and Caucasian population) was conforming to published research. There were a total of 72 comparisons completed for each vertebral segment, totaling to 360 comparisons from C3-C7. In the male population there were a total of 68 correlations, with 14 found in the C3 vertebra, 14 in the C4, 12 in the C5 vertebra, 6 in the C6, and 22 in the C7. For the female population there were a total of 82 significant relationships found, with 14 in the C3 vertebra, 20 in the C4 vertebra, 22 in the C5 vertebra, 14 in the C6 vertebra, and 12 in the C7 vertebra. There were more significant correlations found in the female gender than the male, and these linear relationships are displayed in Tables 14 and 15.

Table 14: CT Male Correlations

	C3			C4			C5			C6			C7		
	m	b	P>F	m	b	P>F	m	b	P>F	m	b	P>F	m	b	P>F
EPWu vs EPWl	0.49	6.95	0.00	0.40	9.02	0.00	0.45	8.51	0.02	0.50	7.77	0.00	0.40	11.25	0.02
EPWu vs EPDu	Not Significant			Not Significant			Not Significant			Not Significant			0.37	14.68	0.03
EPWu vs SCW													0.78	0.77	0.01
EPWl vs EPWu	0.59	9.34	0.00	0.77	6.44	0.00	0.46	12.22	0.02	0.74	8.46	0.00	0.49	15.28	0.02
EPWl vs EPDu	0.30	14.14	0.03	Not Significant			Not Significant			Not Significant			Not Significant		
EPWl vs EPDl	0.26	14.49	0.03												
EPWl vs VBHp	Not Significant												0.83	13.55	0.00
EPWl vs VBHa													1.00	11.80	0.00
EPWl vs SCW													0.66	8.05	0.04
EPDu vs EPWu													0.49	8.33	0.03
EPDu vs EPWl	0.61	4.35	0.03										Not Significant		
EPDu vs EPDl	0.71	3.58	<0.0001	0.71	4.00	<0.0001	0.58	5.83	<0.0001	0.71	4.58	<0.0001	1.03	0.09	<0.0001
EPDu vs SCD	Not Significant			-0.40	22.15	0.04	-0.51	24.29	0.03	Not Significant			Not Significant		
EPDl vs EPWl	0.69	4.05	0.03	Not Significant			Not Significant								
EPDl vs EPDu	0.95	2.07	<0.0001	1.11	-0.80	<0.0001	1.29	-2.87	<0.0001	1.00	1.02	<0.0001	0.76	3.80	<0.0001
EPDl vs SCD	Not Significant			-0.51	24.79	0.04	Not Significant			-0.59	28.24	0.04	Not Significant		
EPDl vs TPW	0.23	4.95	0.02	Not Significant						Not Significant					
VBHp vs EPWl	Not Significant												0.00	6.22	0.33
VBHp vs VBHa	0.94	1.94	<0.0001	0.69	5.12	0.00	0.59	6.84	0.00				<0.0001	3.26	0.82
VBHp vs SCD	Not Significant			Not Significant			Not Significant						0.35	9.19	0.02
VBHp vs TPW				0.18	4.44	0.04							Not Significant		
VBHa vs EPWl				Not Significant									0.00	5.06	0.35
VBHa vs VBHp	0.63	4.51	<0.0001	0.57	5.16	0.00	0.73	2.10	0.00				<0.0001	3.45	0.72
VBHa vs SCW	Not Significant			Not Significant			0.48	-0.23	0.04				0.01	0.80	0.50

Table 14: CT Male Correlations part 2

<table>
<tr><th rowspan="2"></th><th colspan="3">C3</th><th colspan="3">C4</th><th colspan="3">C5</th><th colspan="3">C6</th><th colspan="3">C7</th></tr>
<tr><th>m</th><th>b</th><th>P>F</th><th>m</th><th>b</th><th>P>F</th><th>m</th><th>b</th><th>P>F</th><th>m</th><th>b</th><th>P>F</th><th>m</th><th>b</th><th>P>F</th></tr>
<tr><td>VBHa vs SCD</td><td colspan="3" rowspan="4">Not Significant</td><td colspan="3">Not Significant</td><td colspan="3">Not Significant</td><td colspan="3" rowspan="7">Not Significant</td><td>0.02</td><td>8.70</td><td>0.35</td></tr>
<tr><td>VBHa vs TPW</td><td>0.26</td><td>-1.12</td><td>0.00</td><td>0.23</td><td>-0.09</td><td>0.03</td><td colspan="3">Not Significant</td></tr>
<tr><td>SCW vs EPWu</td><td colspan="3" rowspan="4">Not Significant</td><td colspan="3" rowspan="3">Not Significant</td><td>0.33</td><td>19.67</td><td>0.01</td></tr>
<tr><td>SCW vs EPWl</td><td>0.26</td><td>19.92</td><td>0.04</td></tr>
<tr><td>SCW vs SCD</td><td>0.36</td><td>18.35</td><td>0.00</td><td colspan="3">Not Significant</td></tr>
<tr><td>SCW vs VBHa</td><td colspan="3" rowspan="3">Not Significant</td><td>0.33</td><td>21.94</td><td>0.04</td><td>0.55</td><td>18.97</td><td>0.01</td></tr>
<tr><td>SCD vs EPDu</td><td>-0.38</td><td>21.20</td><td>0.04</td><td>-0.36</td><td>20.83</td><td>0.03</td><td colspan="3" rowspan="3">Not Significant</td></tr>
<tr><td>SCD vs EPDl</td><td>-0.32</td><td>20.44</td><td>0.04</td><td colspan="3" rowspan="6">Not Significant</td><td>-0.27</td><td>20.76</td><td>0.04</td></tr>
<tr><td>SCD vs SCW</td><td>0.80</td><td>-1.52</td><td>0.00</td><td colspan="3" rowspan="4">Not Significant</td><td colspan="3" rowspan="6">Not Significant</td></tr>
<tr><td>SCD vs VBHp</td><td colspan="3" rowspan="2">Not Significant</td><td>0.62</td><td>6.54</td><td>0.02</td></tr>
<tr><td>SCD vs VBHa</td><td>0.64</td><td>6.61</td><td>0.02</td></tr>
<tr><td>TPW vs EPDl</td><td>0.84</td><td>39.16</td><td>0.02</td><td colspan="3" rowspan="3">Not Significant</td></tr>
<tr><td>TPW vs VBHp</td><td colspan="3" rowspan="2">Not Significant</td><td>0.91</td><td>41.56</td><td>0.04</td></tr>
<tr><td>TPW vs VBHa</td><td>1.62</td><td>33.04</td><td>0.00</td><td>0.74</td><td>46.03</td><td>0.03</td></tr>
</table>

Table 15: CT Female Correlations

	C3			C4			C5			C6			C7		
	m	b	P>F	m	b	P>F	m	b	P>F	m	b	P>F	m	b	P>F
EPWu vs EPWl	0.48	7.18	0.01	0.54	6.26	0.00	0.46	7.78	0.00	0.48	7.77	0.02	0.40	10.00	0.02
EPWu vs EPDu	0.53	7.52	0.02	Not Significant			0.40	10.16	0.01	0.37	11.47	0.04	Not Significant		
EPWu vs EPDl	0.54	6.98	0.00	0.38	9.81	0.02	0.35	10.24	0.00	0.38	11.17	0.04			
EPWl vs EPWu	0.86	3.65	0.01	0.79	4.94	0.00	1.00	1.78	0.00	0.69	8.09	0.02	0.83	7.30	0.02
EPWl vs EPDu	Not Significant			0.58	8.90	0.00	0.65	8.25	0.00	0.55	11.32	0.01	0.73	11.62	0.03
EPWl vs EPDl				0.63	7.70	0.00	0.59	8.05	<0.0001	0.60	10.17	0.00	Not Significant		
EPWl vs VBHp	0.82	5.61	0.03	Not Significant			Not Significant			Not Significant					
EPWl vs SCW	Not Significant												1.38	-10.73	0.00
EPWl vs SCD													1.53	1.47	0.01
EPWl vs TPW				0.24	5.42	0.02							Not Significant		
EPDu vs EPWu	0.62	5.10	0.02	Not Significant			0.95	-0.49	0.01	0.69	3.97	0.04			
EPDu vs EPWl	Not Significant			0.76	1.27	0.00	0.72	1.95	0.00	0.71	1.72	0.01	0.37	7.72	0.03
EPDu vs EPDl	0.71	3.73	<0.0001	0.87	0.98	<0.0001	0.62	4.43	<0.0001	0.90	1.13	<0.0001	0.86	2.66	0.00
EPDu vs VBHp	Not Significant			Not Significant			1.25	-0.82	0.00	Not Significant			Not Significant		
EPDl vs EPWu	0.83	2.59	0.00	0.81	2.72	0.02	1.43	-6.22	0.00	0.69	4.47	0.04			
EPDl vs EPWl	Not Significant			0.91	-0.42	0.00	1.11	-3.23	<0.0001	0.76	1.12	0.00			
EPDl vs EPDu	0.93	1.69	<0.0001	0.98	1.24	<0.0001	1.06	0.92	<0.0001	0.89	2.33	<0.0001	0.74	3.76	0.00
EPDl vs VBHp	Not Significant			0.84	4.64	0.04	1.13	2.47	0.05	Not Significant			Not Significant		
VBHp vs EPWl	0.35	7.80	0.03	Not Significant			Not Significant								
VBHp vs EPDu	Not Significant						0.40	6.62	0.00						
VBHp vs EPDl				0.30	8.32	0.04	0.21	8.97	0.05						
VBHp vs VBHa	0.87	2.73	0.00	Not Significant			Not Significant			0.82	3.06	0.00	0.87	2.77	0.00
VBHp vs SCW	Not Significant						0.38	3.02	0.03	Not Significant			Not Significant		
VBHp vs TPW				0.19	3.29	0.01	Not Significant								

Table 15: CT Female Correlations part 2

<table>
<tr><th rowspan="2"></th><th colspan="3">C3</th><th colspan="3">C4</th><th colspan="3">C5</th><th colspan="3">C6</th><th colspan="3">C7</th></tr>
<tr><th>m</th><th>b</th><th>P>F</th><th>m</th><th>b</th><th>P>F</th><th>m</th><th>b</th><th>P>F</th><th>m</th><th>b</th><th>P>F</th><th>m</th><th>b</th><th>P>F</th></tr>
<tr><td>VBHa vs VBHp</td><td>0.73</td><td>2.64</td><td>0.00</td><td colspan="3" rowspan="4">Not Significant</td><td colspan="3" rowspan="2">Not Significant</td><td>0.68</td><td>2.89</td><td>0.00</td><td>0.67</td><td>3.59</td><td>0.00</td></tr>
<tr><td>SCW vs EPWl</td><td colspan="3" rowspan="3">Not Significant</td><td colspan="3" rowspan="11">Not Significant</td><td>0.41</td><td>15.42</td><td>0.00</td></tr>
<tr><td>SCW vs VBHp</td><td>0.80</td><td>15.15</td><td>0.03</td><td colspan="3" rowspan="3">Not Significant</td></tr>
<tr><td>SCW vs SCD</td><td>0.67</td><td>15.49</td><td>0.04</td></tr>
<tr><td>SCW vs TPW</td><td>0.15</td><td>16.48</td><td>0.02</td><td>0.22</td><td>13.22</td><td>0.04</td><td colspan="3" rowspan="2">Not Significant</td></tr>
<tr><td>SCD vs EPWl</td><td colspan="3" rowspan="5">Not Significant</td><td colspan="3" rowspan="2">Not Significant</td><td>0.25</td><td>8.71</td><td>0.01</td></tr>
<tr><td>SCD vs SCW</td><td>0.41</td><td>4.18</td><td>0.04</td><td colspan="3" rowspan="6">Not Significant</td></tr>
<tr><td>SCD vs TPW</td><td>0.21</td><td>3.86</td><td>0.04</td><td>0.25</td><td>1.84</td><td>0.00</td></tr>
<tr><td>TPW vs EPWl</td><td>1.35</td><td>26.50</td><td>0.02</td><td colspan="3" rowspan="3">Not Significant</td></tr>
<tr><td>TPW vs VBHp</td><td>1.99</td><td>24.10</td><td>0.01</td></tr>
<tr><td>TPW vs SCW</td><td>2.06</td><td>-1.34</td><td>0.02</td><td>1.23</td><td>20.32</td><td>0.04</td></tr>
<tr><td>TPW vs SCD</td><td colspan="3">Not Significant</td><td>1.26</td><td>31.96</td><td>0.04</td><td>1.83</td><td>24.83</td><td>0.00</td></tr>
</table>

Moment of Inertia:

The moment of inertia of each vertebral body was found utilizing equation 22 and the measurements for the male and female gender found through the CT measurements. The results of this can be found in Table 16. The values for the density of the vertebra (ρ), mass of the vertebra (m), and moment of inertia of the vertebra (I) (labeled lit) came from previous literature (Paul C. Ivancic 2006; B.L.Riggs 1982). All moment of inertia values, whether using mass and density or from the literature, increase axially through the spine. Values found through the approximation presented in this research using an elliptical frustum match fairly well with the value found in literature for the moment of inertia (Paul C. Ivancic 2006). Figures 16-20 display the measured and predicted values for the male and female population for the specified vertebral level. For the most part it can be seen that the estimate of the moment of inertia for the subjects matches well with the predicted moment of inertia value. There are some outlying points but not always occurring for the same subject. These outlying points are the result of the measured values of the EPWu, EPWl, EPDu, EPDl, and VBH. The values found in literature are larger in the C3, C4, and C7 vertebra than compared to the calculated value for the subject and the expected value of the moment of inertia for the population. This could be a result of the approximation that was accomplished in the moment of inertia when being compared to actual measurements found through lab testing completed by Ivancic and de Jager. The moment of inertia for both genders when viewing the graphs do appear to be fairly similar to each other.

Table 16: Moment of Inertia

	Male				
	C3	C4	C5	C6	C7
EPWu (mm)	16.1696	16.8637	17.5502	19.0973	21.6038
EPWl (mm)	18.8526	19.4674	20.3082	22.6702	25.8844
EPDu (mm)	15.7967	16.225	16.6679	18.1653	18.9517
EPDl (mm)	17.0837	17.156	18.6876	19.1658	18.2543
VBH (mm)	15.2969	14.3189	14.0889	13.6091	14.8092
ρ (kg/m^3)	13.3	13.3	13.3	13.3	13.3
m (kg)	3.63E-02	3.66E-02	3.71E-02	4.39E-02	5.05E-02
I kg m^2 (dens)	1.355E-06	1.3E-06	1.9E-06	2E-06	2.2E-06
I kg m^2 (mass)	1.999E-06	2E-06	2.6E-06	3.1E-06	3.6E-06
I kg m^2 (lit)*	4.50E-06	4.71E-06	4.92E-06	6.86E-06	1.19E-05
	Female				
	C3	C4	C5	C6	C7
EPWu (mm)	15.2337	15.6506	16.0137	17.4355	19.411
EPWl (mm)	16.7738	17.3346	17.8526	20.1583	23.5063
EPDu (mm)	14.4726	14.4521	14.7573	16.0139	16.3149
EPDl (mm)	15.1702	15.4019	16.6202	16.5346	15.788
VBH (mm)	13.6057	12.8782	12.4718	12.3054	14.1328
ρ (kg/m^3)	13.3	13.3	13.3	13.3	13.3
m (kg)	3.63E-02	3.66E-02	3.71E-02	4.39E-02	5.05E-02
I kg m^2 (dens)	8.078E-07	8.8E-07	1.2E-06	1.1E-06	1.4E-06
I kg m^2 (mass)	1.638E-06	1.8E-06	2.3E-06	2.4E-06	2.9E-06
I kg m^2 (lit)*	4.50E-06	4.71E-06	4.92E-06	6.86E-06	1.19E-05

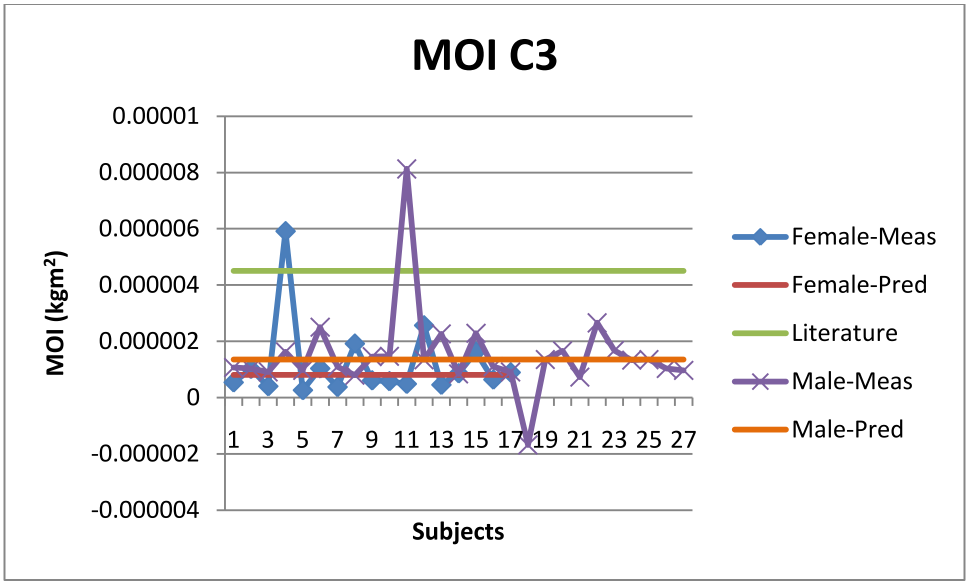

Figure 16: MOI predicted and measured for the C3 vertebra

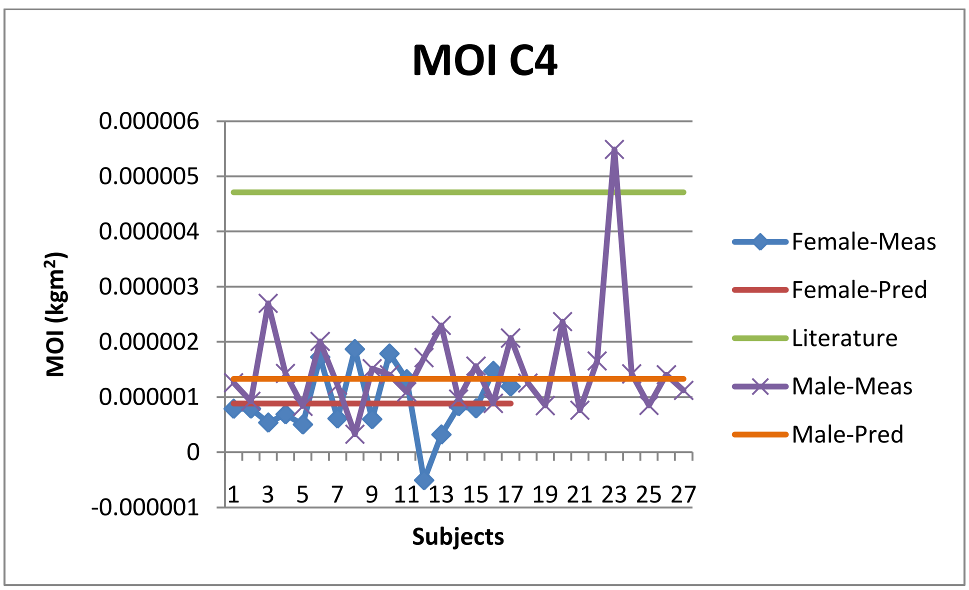

Figure 17: MOI predicted and measured for the C4 vertebra

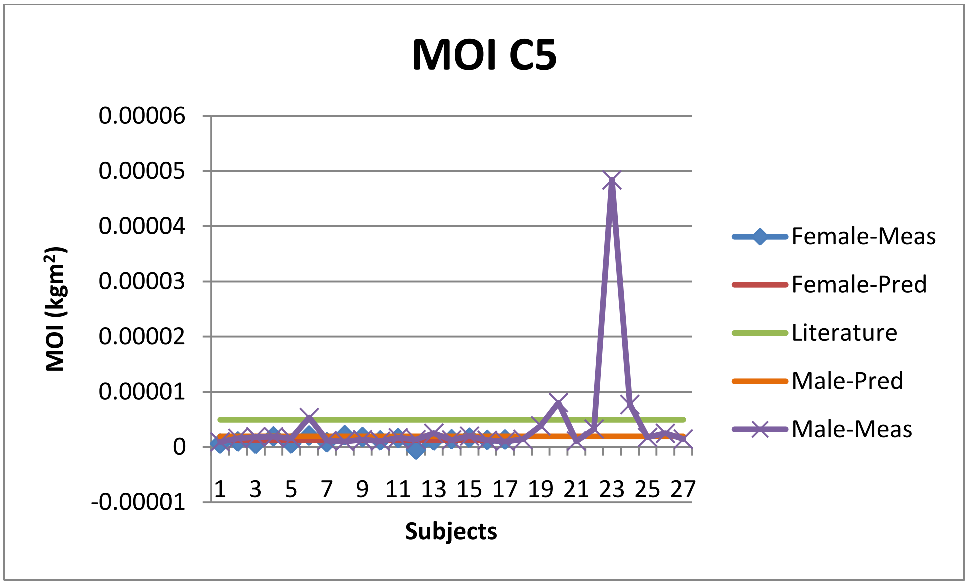

Figure 18: MOI predicted and measured for the C5 vertebra

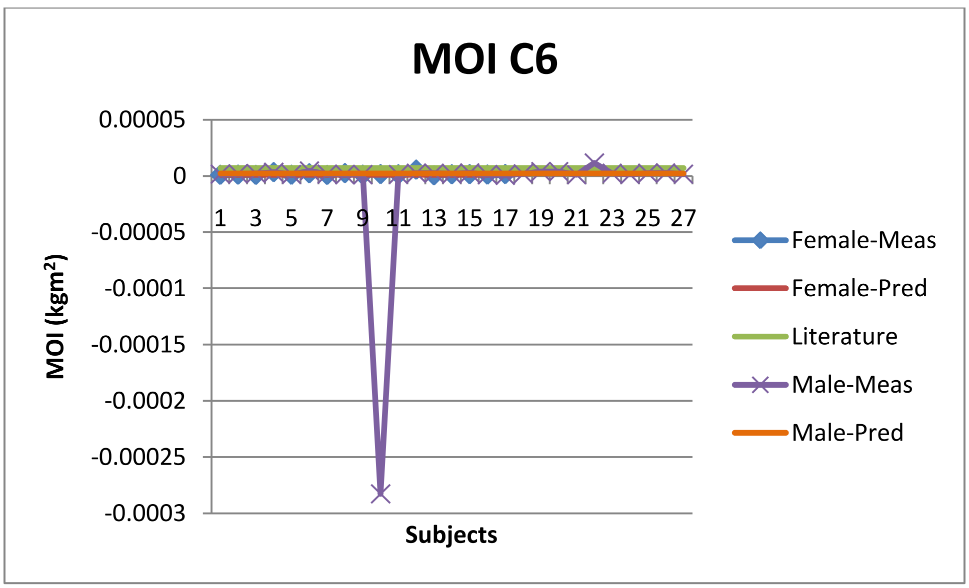

Figure 19: MOI predicted and measured for the C6 vertebra

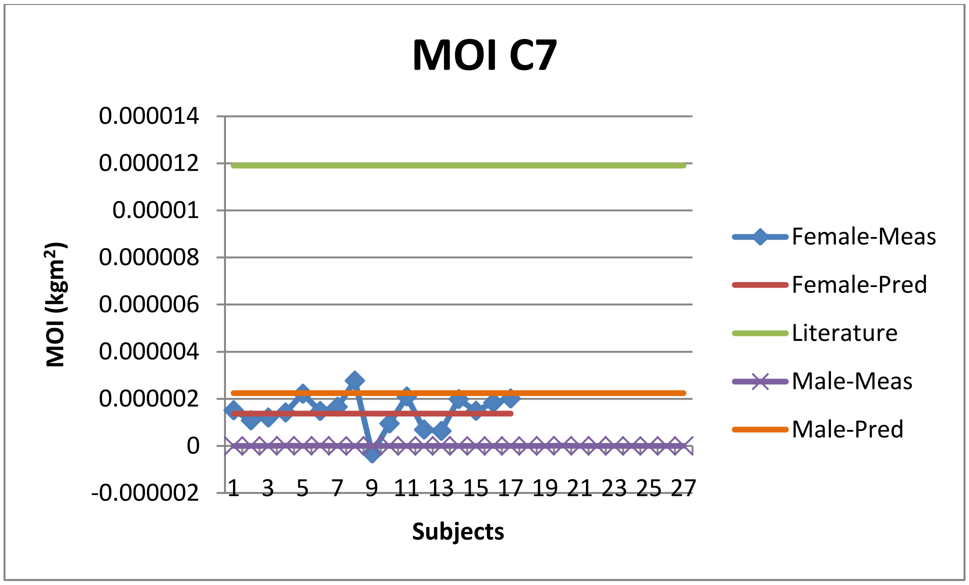

Figure 20: MOI predicted and measured for the C7 vertebra

DISCUSSION

The statistical analysis completed on the measurements of the vertebral dimensions of the Chinese Singaporeans (Tan 2004) resulted in 128 significant relationships. These included 27 in the C3 vertebra, 28 in the C4 vertebra, 25 in the C5 vertebra, 28 in the C6 vertebra, and 20 in the C7 vertebra. The analysis completed on the anthropometric measurements completed by Panjabi on Caucasians found there to be 133 significant correlations. In particular there were 36 in the C3 vertebra, 26 in the C4, 28 in the C5, 18 in the C6, and 26 in the C7. There were a similar amounts of correlations found for both races but the same relationships were not found between them, this could be the result of the significant differences that were found between the two studies.

As stated previously, there was generally no significant difference found between races. For the male population it was found that neither the African American nor Caucasian race exhibited any trend of larger measurements. For the female population, it was found that the Caucasian females exhibited larger dimensions than their African American counterparts (with still no significant difference between them). It was also found that male anthropometric measurements were larger than that of their female counterpart; this phenomenon has been seen in several previous studies. There was a significant difference in the endplate measurements with respect to age from C3-C6, but in the C7 vertebra there was only significant difference in the upper endplate. If there was a difference found in age group it was generally found that the 41-60 age group was similar to the 61+ age group but a difference in the 18-40 age group, this was similar to what was found in the study completed by Liguoro et al. This difference should be taken into consideration when designing intervertebral disc devices. If a device is designed for a middle aged male, it could lead to an improper fit in a young adult male or female which could result in possible failure.

The smallest parameter in both genders was found in the anterior vertebral body height (VBHa). The morphometric parameters with respect to this smallest measurement in the female population are as below:

C3 vertebra:

- EPWu was 1.22 times larger than VBHa
- EPWl was 1.34 times larger than VBHa
- EPDu was 1.16 times larger than VBHa
- EPDl was 1.21 times larger than VBHa
- VBHp was 1.09 times larger than VBHa
- SCW was 1.91 times larger than VBHa
- SCD was 1.41 times larger than VBHa
- TPW was 3.82 times larger than VBHa

C4 vertebra:

- EPWu was 1.33 times larger than VBHa
- EPWl was 1.47 times larger than VBHa
- EPDu was 1.23 times larger than VBHa
- EPDl was 1.31 times larger than VBHa
- VBHp was 1.09 times larger than VBHa
- SCW was 2.03 times larger than VBHa

- SCD was 1.2 times larger than VBHa
- TPW was 4.23 times larger than VBHa

C5 vertebra:

- EPWu was 1.43 times larger than VBHa
- EPWl was 1.6 times larger than VBHa
- EPDu was 1.32 times larger than VBHa
- EPDl was 1.49 times larger than VBHa
- VBHp was 1.12 times larger than VBHa
- SCW was 2.25 times larger than VBHa
- SCD was 1.29 times larger than VBHa
- TPW was 4.58 times larger than VBHa

C6 vertebra:

- EPWu was 1.55 times larger than VBHa
- EPWl was 1.8 times larger than VBHa
- EPDu was 1.43 times larger than VBHa
- EPDl was 1.47 times larger than VBHa
- VBHp was 1.1 times larger than VBHa
- SCW was 2.44 times larger than VBHa
- SCD was 1.31 times larger than VBHa
- TPW was 4.8 times larger than VBHa

C7 vertebra:

- EPWu was 1.48 times larger than VBHa
- EPWl was 1.8 times larger than VBHa

- EPDu was 1.25 times larger than VBHa
- EPDl was 1.21 times larger than VBHa
- VBHp was 1.08 times larger than VBHa
- SCW was 1.93 times larger than VBHa
- SCD was 1.13 times larger than VBHa
- TPW was 4.38 times larger than VBHa

The morphometric parameters with respect to this smallest measurement in the male population are as below:

C3 vertebra:

- EPWu was 1.14 times larger than VBHa
- EPWl was 1.33 times larger than VBHa
- EPDu was 1.11 times larger than VBHa
- EPDl was 1.2 times larger than VBHa
- VBHp was 1.08 times larger than VBHa
- SCW was 1.77 times larger than VBHa
- SCD was 1.3 times larger than VBHa
- TPW was 3.77 times larger than VBHa

C4 vertebra:

- EPWu was 1.27 times larger than VBHa
- EPWl was 1.46 times larger than VBHa
- EPDu was 1.22 times larger than VBHa
- EPDl was 1.29 times larger than VBHa
- VBHp was 1.08 times larger than VBHa

- SCW was 1.89 times larger than VBHa
- SCD was 1.13 times larger than VBHa
- TPW was 4.11 times larger than VBHa

C5 vertebra:

- EPWu was 1.42 times larger than VBHa
- EPWl was 1.64 times larger than VBHa
- EPDu was 1.35 times larger than VBHa
- EPDl was 1.51 times larger than VBHa
- VBHp was 1.14 times larger than VBHa
- SCW was 2.11 times larger than VBHa
- SCD was 1.2 times larger than VBHa
- TPW was 4.46 times larger than VBHa

C6 vertebra:

- EPWu was 1.55 times larger than VBHa
- EPWl was 1.84 times larger than VBHa
- EPDu was 1.48 times larger than VBHa
- EPDl was 1.56 times larger than VBHa
- VBHp was 1.11 times larger than VBHa
- SCW was 2.17 times larger than VBHa
- SCD was 1.26 times larger than VBHa
- TPW was 4.64 times larger than VBHa

C7 vertebra:

- EPWu was 1.53 times larger than VBHa

- EPWl was 1.83 times larger than VBHa
- EPDu was 1.34 times larger than VBHa
- EPDl was 1.29 times larger than VBHa
- VBHp was 1.05 times larger than VBHa
- SCW was 1.89 times larger than VBHa
- SCD was 1.1 times larger than VBHa
- TPW was 4.32 times larger than VBHa

In comparing the measurements completed by the author on the CT images to the previous cadaver studies of both Tan and Panjabi the following results were received (displayed in Tables 17 and 18). In Tables 17 and 18 the following nomenclature applies:

AA = African American (CT measurements)

C-M = Caucasian (CT measurements)

C= Caucasian (Panjabi's measurements)

CS = Chinese Singaporeans (Tan's measurements)

Post-Hoc Analysis:

B: AA is significantly correlated to C-M, but both are significantly different from C and CS

D: AA is significantly correlated to C-M and C but significantly different from CS. C-M, C, and CS are all significantly different from each other.

E: C-M and AA are significantly correlated, C and CS are significantly correlated, but they are not related in any other way.

F: C-M, C, and AA are significantly correlated, and CS and AA are significantly correlated, but otherwise they are significantly different.

H: Only CS is significantly different

J: All are significantly different

G: C-M and C are significantly correlated, but otherwise they are significantly different.

K: C is significantly correlated to C-M and AA, CS is significantly correlated to C-M and AA, and C and CS are significantly different.

L: C and C-M are significantly correlated, AA and CS are significantly correlated, and otherwise they are significantly different

M: CS and AA are significantly correlated, everything else is not.

N: C is correlated with AA and CS, and everything else is significantly different.

O: AA is correlated with C-M and CS, and everything else is significantly different.

P: AA is significantly correlated with C-M, CS, and C, but otherwise everything is significantly different.

Q: C-M is correlated with C and AA, AA is correlated with C-M and CS, otherwise they are significantly different.

R: AA is correlated with C-M and CS, but otherwise not.

S: C and AA are significantly correlated, but otherwise not.

T: AA is correlated with C and CS, and everything else is significantly different.

U: Only C is significantly different.

The correlations between the races differed in the vertebral level and measurement for the male population, shown in Table 17. The EPWu was significantly smaller in the Chinese Singaporeans than the other 3 groups in all vertebral levels except for C6. In C3 and C4 the EPWl was correlated in the African American race and the Caucasian race of the CT measurements, but otherwise they were significantly different. With the Chinese Singaporean race being significantly smaller than Panjabi's Caucasian measurements. The EPDu for the African American male was significantly correlated to both Caucasian populations and all were significantly larger than the Chinese Singaporeans in all vertebrae except for C5. There was no significant difference in the three populations for the VBHa in the C6 vertebra; however the Chinese Singaporeans were significantly smaller than the other two races. The African American male SCW was significantly correlated to both Caucasian populations and all were significantly larger than the Chinese Singaporeans in all vertebrae except for C4. In the C4 vertebra the SCW was significantly smaller in the Chinese Singaporeans than the other three races. The SCD in the C4-C6 vertebra was significantly correlated between the African American male and the Caucasian from the CT measurements, which were significantly smaller than Panjabi's and significantly larger than the Chinese Singaporeans. Finally the TPW in the African American males for the C3, C6 and C7 vertebra was found to be correlated to both Caucasian populations, which were all significantly larger than the Chinese Singaporeans.

Table 17: Correlations between Studies, male

		EPWu	EPWl	EPDu	EPDl	VBHp	VBHa	SCW	SCD	TPW
C3	AA	16.06	19.34	16.58	18.96	14.87	14.01	24.05	15.52	54.80
	C-M	16.18	18.81	15.73	16.93	15.33	14.20	25.13	18.73	53.36
	C	15.72	17.27	14.88	15.61	11.62	NA	23.04	16.15	50.48
	CS	13.79	14.30	13.64	15.02	11.22	10.00	19.36	10.29	41.52
	Post Hoc	H	B	D	J	B	H	D	D	D
C4	AA	17.22	20.90	16.91	17.89	13.64	13.74	25.23	13.63	54.44
	C-M	16.84	19.35	16.17	17.10	14.37	13.27	25.16	15.10	54.67
	C	17.22	17.06	15.22	16.03	11.48	NA	24.62	17.63	48.28
	CS	14.69	15.00	14.03	15.29	11.26	9.88	19.38	10.44	44.94
	Post Hoc	H	B	D	B	E	H	H	B	B
C5	AA	17.24	22.09	17.25	19.52	13.73	12.50	25.18	14.03	57.90
	C-M	17.58	20.17	16.62	18.62	14.12	12.37	26.14	14.95	55.01
	C	17.63	19.35	15.14	17.84	11.42	NA	24.68	17.42	47.42
	CS	14.89	15.89	14.35	15.12	11.29	9.60	20.24	10.26	47.61
	Post Hoc	H	J	B	D	E	H	D	B	E
C6	AA	19.70	21.47	17.70	20.40	14.65	10.52	26.28	14.40	55.48
	C-M	19.05	22.77	18.20	19.07	13.53	12.45	26.79	15.60	57.28
	C	18.39	22.04	16.51	18.31	10.84	NA	25.62	18.26	49.87
	CS	15.80	19.55	14.58	15.76	11.33	10.40	20.51	10.27	48.41
	Post Hoc	D	F	D	D	B	No Diff	D	B	D
C7	AA	21.33	23.27	19.30	19.33	14.14	12.92	26.52	13.85	61.30
	C-M	21.63	26.09	18.92	18.17	14.86	14.23	26.75	15.76	61.04
	C	21.89	23.89	18.07	16.81	12.79	NA	24.50	15.45	66.42
	CS	19.02	20.36	15.06	15.57	11.83	11.18	19.69	10.95	54.03
	Post Hoc	H	D	D	B	D	H	D	F	D

As for the female populations, there is again a difference in correlations due to race and vertebral level even more so than the males (shown in Table 18). There are less trends seen in the female group than the male group. One trend is found in the VBHa where the Chinese Singaporean female is significantly smaller than the other two groups, who do have significant correlation in the C3, C5, and C7 vertebrae. Another trend found in the SCW similar to the VBHa where the Chinese Singaporeans were significantly smaller than the other three, which were all correlated in all vertebral levels except for C6.

Table 18: Correlations between Studies, female

		EPWu	EPWl	EPDu	EPDl	VBHp	VBHa	SCW	SCD	TPW
C3	AA	14.92	15.34	14.22	15.30	13.33	12.51	22.90	16.15	44.55
	C-M	15.37	17.37	14.58	15.12	13.72	12.54	24.19	18.14	49.05
	C	15.71	17.27	14.88	15.61	11.62	NA	23.04	16.15	50.48
	CS	13.79	14.30	13.64	15.02	11.22	10.00	19.36	10.29	41.52
	Post Hoc	H	G	F	K	B	H	H	D	L
C4	AA	14.64	16.71	14.55	15.31	12.09	11.14	23.42	13.20	46.88
	C-M	16.07	17.59	14.41	15.44	13.21	12.05	24.12	14.51	50.74
	C	17.22	17.06	15.22	16.03	11.48	NA	24.62	17.63	48.28
	CS	14.69	15.00	14.03	15.29	11.26	9.88	19.38	10.44	44.94
	Post Hoc	M	H	K	K	N	J	H	J	F
C5	AA	15.70	17.35	14.44	16.04	12.08	11.04	24.51	13.61	48.11
	C-M	16.15	18.06	14.89	16.86	12.64	11.22	25.33	14.66	52.20
	C	17.63	19.35	15.14	17.84	11.42	NA	24.68	17.42	47.42
	CS	14.89	15.89	14.35	15.12	11.29	9.60	20.24	10.26	47.61
	Post Hoc	O	G	K	O	E	H	H	G	P
C6	AA	16.60	19.03	14.94	15.52	11.69	10.87	24.75	13.70	49.84
	C-M	17.78	20.63	16.46	16.96	12.56	11.38	28.25	15.07	55.19
	C	18.39	22.04	16.51	18.31	10.84	NA	25.62	18.26	49.87
	CS	15.80	19.55	14.57	15.76	11.33	10.40	20.51	10.27	48.41
	Post Hoc	Q	O	L	O	M	R	S	J	T
C7	AA	19.11	22.07	14.84	15.09	13.22	12.72	24.47	13.46	54.34
	C-M	19.54	24.11	16.93	16.08	14.51	13.25	25.61	15.29	58.49
	C	21.89	23.89	18.07	16.81	12.79	NA	24.50	15.45	66.42
	CS	19.02	20.36	15.06	15.57	11.83	11.18	19.69	10.95	54.03
	Post Hoc	U	F	M	U	N	H	H	H	O

In all measurements in all vertebral levels the Chinese Singaporeans were smaller, not always statistically significant, than the other three races. There is more correlation based on vertebral level and dimensional anatomy than anything else.

Utilizing the results from the vertebral analysis on the CT measurements (Tables 14 and 15) a computer program can be created with the user input of some anthropometric measurements. A program has been started for the C3 vertebra and the male population that completes this task, continuation of this can be accomplished through C7 and for the female population. The program requires for the EPWl, VBHa, and SCD to be measured by the user on the CT image of the patient. The flowchart of how the program works is provided below and in Figure 21. This program will output values for all 9 measurements (EPWu, EPWl, EPDu, EPDl, VBHp, VBHa, SCW, SCD, and TPW) as described by the linear mathematical relationships found from the vertebral statistical analysis.

1. First the user is asked if they would like to know a measurement for the C3 vertebra, in this example the EPWl.
   - I. No (go to step 2)
   - II. Yes
     - A. If this measurement was found previously, the user will be asked if they would like to use with what was found previously or if they would like to calculate it.
       - a. If a measurement can be found multiple ways the user is asked which way they would like to find the measurement. For example the user wants to find the EPWl for the C3 vertebra. The EPWl can be found based on the EPWu, EPDu, or the EPDl. The program then requests if the user would like to calculate the EPWl based on any of these options. The program calculates the answer based on the user input.
         - i. Assuming the user wants to calculate the EPWl based on the EPDu, and if the EPDu was found previously the user will be asked if they would like to calculate the EPWl based on the previously found EPDu or on a new measurement; but if EPDu was not found previously it will ask the user to input the measurement so that EPWl can be found.

ii. Utilizing the previous answer of calculating the EPWl based on the EPDu if there are other measurements that can be found based off the EPDu they will also be found here. For example in the C3 vertebra if EPDu is input the EPDl can be found so if EPDu is given it will calculate EPDl as well.

2. The user is asked if they would like to find the next measurement, until it reaches the end of the available measurements
3. An output of the image is created along with an output file containing the measurements found along with the mean and standard deviation of the measurements.

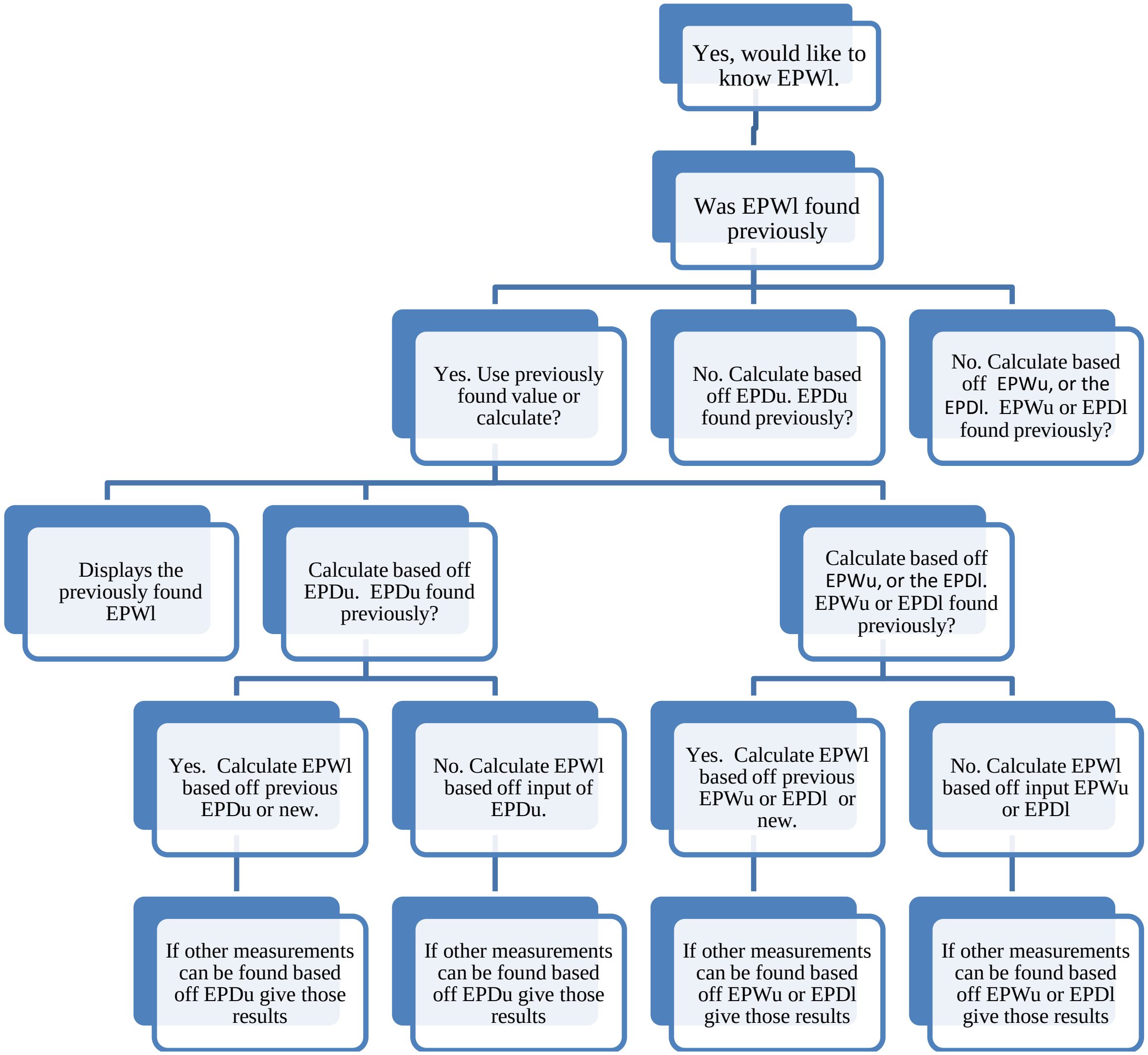

Figure 21: Flow chart of how step II works

CONCLUSION

The analysis of the vertebral anthropometrics in the cervical spine for the Chinese Singaporean race resulted in 600 total comparisons being completed in each vertebral body from C3-C7, resulting in 3000 comparisons in total being done. In this analysis it was found that there were 27 significant correlations in the C3 vertebra, 28 in the C4 vertebra, 25 in the C5 vertebra, 28 in the C6 vertebra, and 20 in C7 vertebra which is a total of 128 relationships found from C3 to C7. This results in only about 4.267% of the 3000 comparisons being significant. For the Caucasian analysis, there were a total of 2760 comparisons from C3-C7 of these only 133 were found to be significant, 35 in the C3 vertebra, 26 in C4, 28 in C5, 18 in C6, and 26 in the C7 vertebra. This results in only about 4.82% of the 2760 comparisons being significant. An important result of these findings is the new mathematical models developed between the different dimensional anatomy with respect to both race, and gender. The results of these findings can also help to improve spine modeling.

The analysis of the CT measurements showed more significant differences with respect to gender rather than race (African American/Caucasian), and there to be significant difference in age for the measurements of the endplate. The vertebral analysis (resembling what was completed for Chinese Singaporeans and Caucasians) resulted in a total of 68 total relationships for the male population (18.89%), and 82 significant correlations for the female population. Out of the total of 360 comparisons that were completed, this results in 18.89% and 22.78% significant correlations for the male and female population respectively. It is important to mention that the sample size of the subjects involved is not large enough to draw conclusions about the population.

A mathematical model for the moment of inertia of the vertebral body was developed, and results corresponded to what was found in previous literature. This will assist in the understanding of moment and force transmission through the body, along with how it resists bending.

With the differences that were found based on age and gender, it is important to take them into consideration while completing device design. While patient specific design of a device would be ideal, this is not logical because of cost issues. Thus gender and age considerations must be taken into account.

This analysis is being used in current research to produce more accurate cervical spine models for spinal implants and risk assessment. The results of the analysis will help uncover the connected between certain diseases with specific spinal alignments and why a subjects' spine was more susceptible to failure. Lastly this analysis will clarify the functionality of the cervical spine.

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