Mid-sagittal Dimensions of Cervical Vertebral Bodies

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KEY WORDS   Radiograph · Cervical spine · Vertebral body ·
Ponderal index · Head weight.

ABSTRACT   A series of lateral radiographs of the cervical spinal column
was evaluated in order to determine vertebral body dimensions. The sample
included males (N = 30) and females (N = 31) 18 to 24 years old, comprising
three stature percentile ranges (1–20; 40–60; 80–99) of the U. S. adult popula-
tion. A two-dimensional analysis of vertebral body height (average distance
between superior-inferior surfaces), depth (average distance between anterior-
posterior surfaces), and area (average height × average depth) revealed mini-
mal effects due to stature. In all subjects, average depth exceeded average
height for vertebral bodies C3 through C7. Upon combining stature groups,
both sexes revealed maximum average values for these dimensions at the
seventh cervical vertebral body. Minimum average height occurred at C5
whereas minimum average depth was found at C3. Significant correlation
($\alpha < 0.05$) was found for males between ponderal index and height and depth
of the C7 vertebra. Male head weight correlated significantly with C3, C4,
C5 and C6 vertebral body height and with C3, C5 and C6 vertebral body depth.
For females, C7 height and C6 depth correlated significantly with ponderal
index and head weight respectively. Probable biomechanical relationships of
specific cervical vertebral bodies are noted.

Increased research emphasis on the cer-
vical spinal column may be attributed to
the increase in neck injuries of "whiplash"
type (Van Eck et al., '73). Although the
anthropometrical and anatomical literature
refers to vertebral body growth under nor-
mal and abnormal stress (Gooding and
Newhauser, '65), to weights of particular
components of the human vertebral col-
umn (Lawrance and Latiner, '67), and to
total areas of the cord in various primates
(Schon and Straus, '69), little information
is available concerning actual dimensions
of vertebral bodies of the cervical spine.
Information providing cervical vertebral
body size in the mid-sagittal plane became
available as a result of the "Bio-engineer-
ing Study of Basic Physical Measurements
related to Susceptibility to Cervical Hyper-
extension-Hyperflexion Injury," conducted
at the Highway Safety Research Institute,
University of Michigan (Snyder, Robbins
and Chaffin, '72; Foust et al., '73).[3] The

study used human volunteer subjects of
both sexes, 18 to 74 years old, selected as
representative of the U. S. adult population
according to the Department of HEW, Na-
tional Center for Health Statistics (Stoudt
et al., '65). All subjects were treated in
accordance with the guidelines of the In-
stitutional Guide to DHEW Policy on Pro-
tection of Human Subjects.

MATERIALS AND METHODS

A major portion of the cervical neck study
involved a two-dimensional analysis of lat-
eral radiographs of the cervical portion of
the spinal column to determine ". . . mea-
surements such as vertebral interspaces,
bone to skin surface dimensions and neck
angles . . ." (Snyder et al., '72: p. 38).
Three right lateral views were taken for
each subject (fig. 1): (1) a neutral sitting
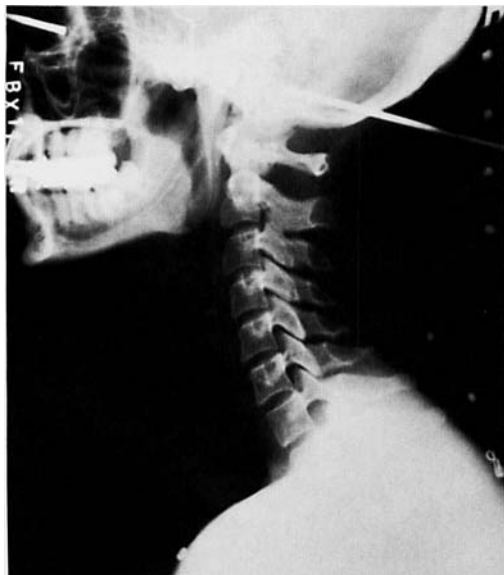position, (2) maximum voluntary flexion,

Fig. 1   Lateral radiograph of subject in neutral position. Rod oriented through nasion and tragion defines head position in relation to the vertical marker.

and (3) maximum voluntary extension. The subject was X-rayed in these positions while maintaining a relaxed seated posture in an unpadded chair with a seat back angle of 13° from vertical and a seat pan angle of 6° from horizontal (Snyder et al., '72). Radiographs were taken utilizing a Picker KM 200 Centurian II X-ray generator. The exposures were taken on 10 × 12 inch film with a tube-to-film distance of 60 inches. A small pendulum, marked in inches with lead shot, was positioned in the mid-sagittal plane and exposed in each film to provide a correction factor for magnification. The neutral-position films for 61 young subjects were analyzed to provide the data reported herein. Errors due to subject orientation and parallax are assumed to be constant. For each radiograph the cervical vertebral bodies were each marked (fig. 2) in the mid-sagittal plane according to the following definitions (Meschan, '68).

1. Most superior-anterior point.
2. Most superior-posterior point.
3. Most inferior-anterior point.
4. Most inferior-posterior point.

For each vertebra, the dimension of height (inferior-superior direction) was cal-

culated by averaging the values of the segments defined as the distance between points (1, 3) and (2, 4). Similarly, depth (anterior-posterior direction) was defined as an average of the line segments (1, 2) and (3, 4). (Although true linearity does not exist for each vertebral body as described, similarities in shape between C3 through C7 minimize errors based upon the above approach.) Area was defined as the product of height and depth. All dimensions were obtained directly from the films using a Vernier caliper to the nearest tenth of a millimeter. Atlas and axis vertebrae were not included in this study because of their specialized shape and function.

Subject selection for the primary neck study was based upon sex, age, and stature and was designed to obtain a representative sampling of the United States adult population. Subject participation was based on approval of a previously-submitted health questionnaire. However, due to age-associated changes (e.g. arthritis) commonly detected in many older subjects, and the consequent introduction of error due to abnormal vertebral body shape, only the young age group (18–24 years) was analyzed for this study. No effort was made to achieve a racial balance (of the subjects reported herein, one was Black American, two were Oriental American and the remainder were White). Age being constant, the two primary variables analyzed were sex and stature (Snyder et al., '72). The resultant 2 × 3 matrix of data cells is shown in table 1.

A minimum of ten subjects, selected at random, were analyzed in each category. Occasionally, however, the seventh cervical vertebra could not be properly outlined thus resulting in a sample size of nine as reported in a few of the data cells in tables 2–7.

RESULTS

Dimensions of vertebral body height, depth and area were derived for each vertebra as described in the MATERIALS AND METHODS section and are reported in tabular form below. Average values and 95% confidence limits for each data cell are presented in graphic form in figure 3. The following observations relate to these data.

Height (Tables 2, 3)

1. Males have greater vertebral body heights, C3 through C7 (as seen in all stature groups), when compared to the corresponding female dimensions. 2. For all subjects, there is a progressive decrease in average vertebral body height from C3 through C5, and a progressive increase in height from C5 to C7 with the exception of C6 in the male 40–60% ile stature group. Minimum average height for both sexes is found at C5. In all cases the seventh cervical vertebral body has the largest average height. 3. Neither males nor females reveal a consistent trend for height between stature percentiles. However, both sexes do attain maximum average values for height, in all vertebrae, in the 80–99% ile (except females' C3).
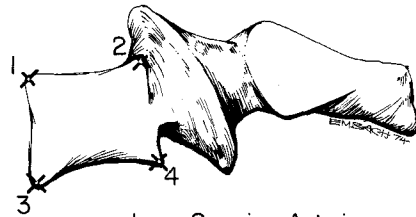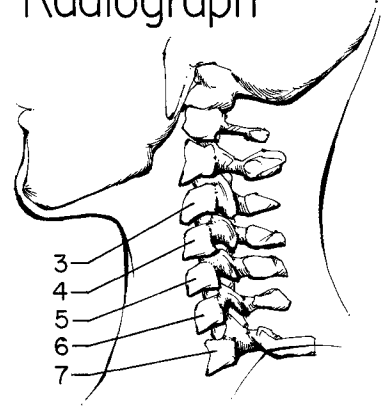
Depth (Tables 4, 5)

1. The average depth for each male cervical vertebral body exceeds similar female dimensions from corresponding stature percentiles. 2. For all subjects, minimum values for vertebral body depth occur at C3. A progressive increase is noted for males with maximum depth attained at C7. Females in the 1–20% ile reveal a similar trend whereas maximum depth values occur at levels C6 and C7 in the two remaining female stature groups. 3. The depth of male vertebral bodies increases with body stature, with maximum average values reached in the 80–90% ile for each vertebra. Females do not reveal similar stature differences.

For both males and females, the average depth is greater than the average height in all cases.

Area (Tables 6, 7)

1. Males have larger average vertebral body areas (noted for all stature groups) when compared to the corresponding values for females. 2. For males only, there is a consistent but slight decrease in area from C3 to C5. Females do not exhibit any apparent trends in these vertebrae. In both sexes, there is a progressive increase in area from C5 to C7, with maximum average values attained at C7. 3. In both male and female populations there is a progressive increase in average vertebral body area, from a minimum in the 1–20% ile

Depiction of Cervical Spine Radiograph

1..........Superior–Anterior

2.........Superior–Posterior

3........Inferior–Anterior

4.........Inferior–Posterior

Fig. 2   Method of marking vertebral body for determining the dimensions of height and depth.

TABLE 1

Subject stature categories

Subject	Age (yr.)	Stature (cm)	% ile of population [1]
Male	18–24	159 –169	1–20
		172.5–169	40–60
		180 –190	80–99
Female	18–24	148.2–156.5	1–20
		160 –164	40–60
		167.5–176	80–99

[1] Based upon U. S. Dept. of Health, Education and Welfare "Weight, Height and Selected Body Dimensions of Adults," U. S. 1960–62. National Center for Health Statistics No. 1000, Series 11, No. 8. Table 2, p. 27.

to a maximum in the 80–90% ile. Of both sexes, one exception is that of C6 in which the minimum area is found in the 40–60% ile.

TABLE 2

Height of male cervical vertebral bodies (cm)

Ver-tebral body	1–20% ile				40–60% ile				80–99% ile			
	N	X̄	S.D.	C.V.[1]	N	X̄	S.D.	C.V.	N	X̄	S.D.	C.V.
C3	10	1.24	0.05	4.4	10	1.26	0.08	6.6	10	1.37	0.08	6.0
C4	10	1.18	0.11	9.1	10	1.22	0.07	6.0	10	1.34	0.07	5.2
C5	10	1.15	0.10	9.1	10	1.14	0.09	7.9	10	1.28	0.11	8.5
C6	10	1.18	0.12	10.2	10	1.13	0.09	7.7	10	1.29	0.09	6.6
C7	10	1.33	0.10	7.8	9	1.34	0.07	5.1	9	1.44	0.11	7.6

[1] % C.V. $= \dfrac{\text{S.D.}}{\text{X}} \times 100.$

TABLE 3

Height of female cervical vertebral bodies (cm)

Ver-tebral body	1–20% ile				40–60% ile				80–99% ile			
	N	X̄	S.D.	C.V.[1]	N	X̄	S.D.	C.V.	N	X̄	S.D.	C.V.
C3	11	1.11	0.09	7.7	10	1.14	0.09	7.5	10	1.12	0.11	10.1
C4	11	1.07	0.09	8.9	10	1.10	0.10	8.8	10	1.11	0.12	11.0
C5	11	1.06	0.08	7.5	10	1.07	0.07	6.9	10	1.10	0.11	10.5
C6	11	1.08	0.08	7.8	10	1.08	0.07	6.4	10	1.15	0.08	6.7
C7	11	1.17	0.10	8.7	10	1.25	0.09	6.8	10	1.29	0.07	5.8

[1] % C.V. $= \dfrac{\text{S.D.}}{\text{X}} \times 100.$

TABLE 4

Depth of male cervical vertebral bodies (cm)

Ver-tebral body	1–20% ile				40–60% ile				80–99% ile			
	N	X̄	S.D.	C.V.[1]	N	X̄	S.D.	C.V.	N	X̄	S.D.	C.V.
C3	10	1.33	0.07	5.0	10	1.42	0.12	8.3	10	1.47	0.15	10.4
C4	10	1.38	0.08	6.0	10	1.44	0.07	4.6	10	1.50	0.12	7.8
C5	10	1.41	0.11	8.0	10	1.45	0.04	3.1	10	1.54	0.09	5.5
C6	10	1.47	0.12	8.4	10	1.53	0.07	4.5	10	1.60	0.07	4.1
C7	10	1.48	0.11	7.5	9	1.55	0.08	5.2	9	1.61	0.09	5.7

[1] % C.V. $= \dfrac{\text{S.D.}}{\text{X}} \times 100.$

A series of statistical tests was performed on the observations noted above. A two-way analysis of variance was performed for height, depth, and area for each vertebra to compare the effects of stature and sex. Analysis of variance tables were constructed for each test, and the appropriate F statistics calculated. No statistically significant differences were noted for stature. However, statistically significant differences for sex at the 0.05 significance level were observed for vertebrae C3 (depth; area), C4 (depth), C6 (depth; area) and C7 (height; depth; area). Since analysis of variance indicated no stature effects but possible sex differences, the three stature groups were combined for each vertebra and a "t" test was performed. Exceptions to many of the trends outlined previously disappear upon combining stature groups within each sex category. The "t" statistics reveal that, in every case, males are significantly larger than females ($\alpha < 0.05$). This result is not surprising, since stature groups were selected as percentiles of the population rather than directly compared between sexes of similar statures. Future work might seek to compare vertebral body sizes for females and males of similar stature to test for significant differences in size based on sex. No such calculation was attempted in the present study.

The functional adaptation of bone to tensile and/or compressive stresses has been

TABLE 5

Depth of female cervical vertebral bodies (cm)

Ver-tebral body	1–20% ile				40–60% ile				80–99% ile			
	N	$\overline{X}$	S.D.	C.V.[1]	N	$\overline{X}$	S.D.	C.V.	N	$\overline{X}$	S.D.	C.V.
C3	11	1.22	0.13	10.62	10	1.20	0.11	8.8	10	1.24	0.10	8.0
C4	11	1.28	0.15	11.65	10	1.25	0.08	6.1	10	1.26	0.11	9.1
C5	11	1.31	0.13	10.34	10	1.31	0.11	8.2	10	1.30	0.12	9.2
C6	11	1.35	0.15	11.22	10	1.37	0.14	10.0	10	1.40	0.11	8.3
C7	11	1.37	0.14	10.10	10	1.37	0.11	7.8	10	1.40	0.09	6.4

[1] % C.V. $= \dfrac{\text{S.D.}}{\overline{X}} \times 100.$

TABLE 6

Area of male cervical vertebral bodies (cm)

Ver-tebral body	1–20% ile				40–60% ile				80–99% ile			
	N	$\overline{X}$	S.D.	C.V.[1]	N	$\overline{X}$	S.D.	C.V.	N	$\overline{X}$	S.D.	C.V.
C3	10	1.65	0.13	7.6	10	1.78	0.15	8.7	10	2.01	0.22	10.8
C4	10	1.63	0.16	9.8	10	1.76	0.10	5.5	10	2.01	0.20	9.8
C5	10	1.62	0.20	12.4	10	1.66	0.14	8.5	10	1.97	0.20	10.4
C6	10	1.74	0.20	11.3	10	1.71	0.15	8.6	10	2.07	0.20	9.6
C7	10	1.96	0.21	10.9	9	2.08	0.18	8.8	9	2.33	0.23	9.9

[1] % C.V. $= \dfrac{\text{S.D.}}{\overline{X}} \times 100.$

TABLE 7

Area of female cervical vertebral bodies (cm)

Ver-tebral body	1–20% ile				40–60% ile				80–99% ile			
	N	$\overline{X}$	S.D.	C.V.[1]	N	$\overline{X}$	S.D.	C.V.	N	$\overline{X}$	S.D.	C.V.
C3	11	1.36	0.19	13.6	10	1.38	0.20	14.6	10	1.40	0.23	16.1
C4	11	1.37	0.22	15.8	10	1.38	0.19	13.9	10	1.41	0.26	18.6
C5	11	1.36	0.19	13.9	10	1.40	0.19	13.0	10	1.45	0.27	18.6
C6	11	1.47	0.25	16.6	10	1.44	0.14	9.6	10	1.61	0.23	14.3
C7	11	1.62	0.26	15.9	10	1.68	0.22	12.9	10	1.81	0.21	11.4

[1] % C.V. $= \dfrac{\text{S.D.}}{\overline{X}} \times 100.$

employed as a useful hypothesis in the study of bone growth and development (Evans, '57). The intent, therefore, was to relate dimensions of the cervical vertebral bodies to stresses of probable consequence. The subsequent comparison employed measures of head weight and body build as indicators of forces acting upon the spinal column. Head weight was calculated from the following regression equation derived by Clauser et al. ('69: p. 46):

Head weight = 0.104 (head circumference)
+ 0.015 (body weight) − 2.189.

A measure of body build was taken as the ponderal index (height/^{3} $\sqrt{\text{weight}}$). Although a less accurate measure of build in

the . . . "later decades of life . . ." (Sheldon et al., '40: pp. 265–266), the ponderal index remains a reliable guide in the younger age groups (18–24 years) pertinent to this study (Heath, '63).

Results obtained from correlating head weight and ponderal index with height and depth of vertebral bodies C3 through C7 are presented in table 8. (The variation in vertebral body size explained by head weight and ponderal index is equivalent to r^2.) Correlation coefficients significant at $\alpha < 0.05$ were found for the following:

1. Male ponderal index: C7 height and depth;
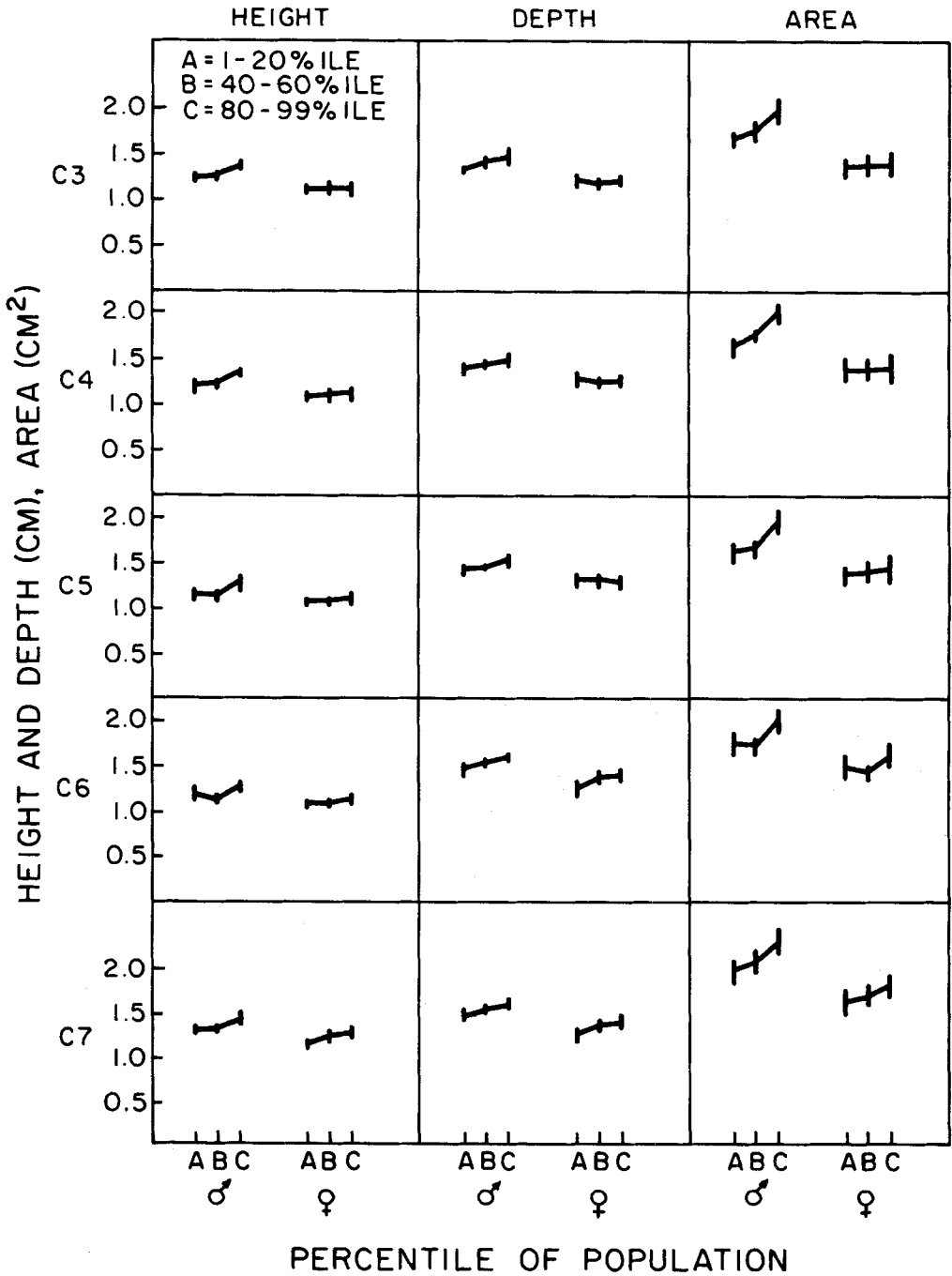2. Male head weight: C3, C5 and C6 height and depth, and C4 height;

Fig. 3   Average vertebral body dimensions and 95% confidence intervals according to sex and stature.

Correlation coefficients for indices of stress with vertebral body height and depth

	Male		Female	
	H.W.	P.I.	H.W.	P.I.
C3 Height	0.4740 [1]	0.2221	0.2629	0.1791
C4 Height	0.4034 [1]	0.2911	0.2150	0.2596
C5 Height	0.4570 [1]	0.1554	−0.0542	0.3137
C6 Height	0.4365 [1]	0.0543	0.0219	0.3644
C7 Height	−0.2728	0.4528 [1]	0.2568	0.5063 [1]
C3 Depth	0.4074 [1]	−0.0112	0.2625	0.1533
C4 Depth	−0.3309	0.1074	0.1619	0.0931
C5 Depth	0.3928 [1]	0.0634	0.2988	0.1190
C6 Depth	0.4012 [1]	0.1484	0.3950 [1]	0.2741
C7 Depth	−0.3308	0.4406 [1]	0.3522	0.2396

P.I., Ponderal index.
H.W., Head weight.
[1] ($\alpha = 0.05$).

3. Female ponderal index: C7 height;
4. Female head weight: C6 depth.

CONCLUSION

The study reported herein has provided previously unavailable dimensional information concerning the third through seventh cervical vertebrae. Two-dimensional mid-sagittal measurements of the human cervical spine, the effects of sex and stature on these measurements, and the presence of size trends within the spinal column are of value to researchers investigating various aspects of the spine. The data presented demonstrate that although there are no significant stature differences:

1. Average vertebral body depth exceeds that of height for both sexes.
2. Upon combining stature groups, the vertebral body of C7 was found to have the largest average height and depth for both males and females; the smallest average values are found in C5 for height and C3 for depth. Male vertebrl body area also attains minimum values at C5. Data from Snyder, Chaffin and Shutz's ('72) study of cervical vertebral interspaces, in the determination of cervical spine mobility, reveal trends similar to those outlined above. As these authors have indicated, vertebrae C3 through C5 are most consistently affected by head inclination, unlike the vertebrae below ('97: pp. 81–88). The present study has yielded further evidence as to the "pivotal" nature of C5. The casual observation of increasing vertebral body size as one descends the spinal

column must now be refined to include specific variations within particular segments of the spine.

3. Males exceed females, to a statistically significant degree, in the dimensions of height, depth and area for cervical vertebral bodies C3 through C7.
4. The seventh cervical vertebral body has the largest average mid-sagittal cross-sectional area for both males and females.
5. Upon testing for possible relationships between stress indication and vertebral body size, ponderal index was found to correlate at the 5% significance level with the height and depth of the males' seventh cervical vertebral body, and with the height of the females' C7 body. Male head weight correlates significantly with C3 for depth. Male vertebral body area and with C3, C5 and C6 vertebral body depth. Female head weight correlates significantly with C6 vertebral body depth. In contrast to previously held assumptions, the seventh cervical vertebra's response to head weight appears minimal, whereas the effects of overall body build take on added significance. Further evaluation of both thoracic and cervical vertebrae may reveal that C7 is influenced more by forces known to affect the vertebrae directly beneath it rather than those above it.

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