An Anthropometric Visualization of the Pediatric Head, Neck and Shoulders in Consideration of Cervical Spine Immobilization

by

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Abstract

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This study is geared toward visually describing the anthropometry (comparative measurements) of the pediatric head, neck and shoulder complex (HNSC) in consideration of cervical spine immobilization, over a range of ages. While it is a truism that children are not miniature adults, there are no population based data demonstrating the anthropometric dimensions and proportions of children in consideration of neutral position. These data are necessary for the appropriate design of equipment used in the emergency environment for cervical spine immobilization of children. The goal of this project is to develop a visualization of the proportions and trends in pediatric HNSC growth as it relates to age, height and weight.

In this cross-sectional study, nine anthropometric measurements of the HNSC of 128 infants and children, aged 0-14, were collected using simple measuring instruments. The numerical data were analyzed to ensure normal distribution, determine correlation coefficients and create scatter plots. The data were expanded with relevant overlapping portions of existing anthropometric data.

The basic proportions of the pediatric HNSC were illustrated using limited measurements to form geometric outline diagrams. These HNSC box diagrams were constructed to represent observations (individuals), averages, and predicted averages. The predicted averages HNSC box diagrams when arranged together, visualize HNSC growth as height changes. Height was chosen to represent growth most accurately because it was determined to be the best predictor of neck height, when comparing height, age and weight.

Visual representation of the numerical data provide a graphical representation of the changes in the size and shape of the pediatric HNSC according to age, height and anthropometric measurements of the HNSC. Accurate visual descriptions of pediatric HNSC anthropometry may be applied to interdisciplinary development of an effective immobilization device for acute care of critically injured children.

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Introduction

Significance

Children are not miniature adults (Huelke). Their proportions do not change symmetrically with growth (Herzenberg) as seen in Figure 1. This study addresses the size and shape of the head, neck and shoulder complex (HNSC) of infants and children under fourteen years of age.

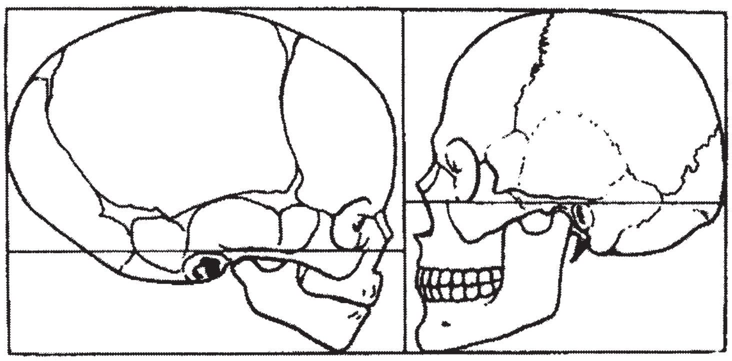


Figure 1.
A comparison of the face-braincase proportions in the child and the adult. The horizontal line (also referred to as the Frankfort Plane) passes through the same anatomical landmarks on both skulls.Reprinted from Donald F.Huelke. *An Overview of Anatomical Considerations of Infant and Children in the Adult World of Automobile Safety, from the 42nd Annual Proceedings of the Association for the Advancement of Automobile Medicine.*

Concerns have been raised by emergency medicine physicians that pediatric proportions do not appear to be properly addressed in the design of specific immobilization devices used in the emergency setting. Suspected neck injury necessitates the use of cervical spine immobilization for patient transport. The devices used for achieving cervical spine immobilization are intended to support the spine and prevent further injury. Cervical spine collar dimensions currently in use may not relate to the size and shape of the children for which they were designated (Figure 2). Older children are often placed in collars designated for infants, while infants are either not placed in a collar, or placed in one that is designated for them but does not appear appropriate.

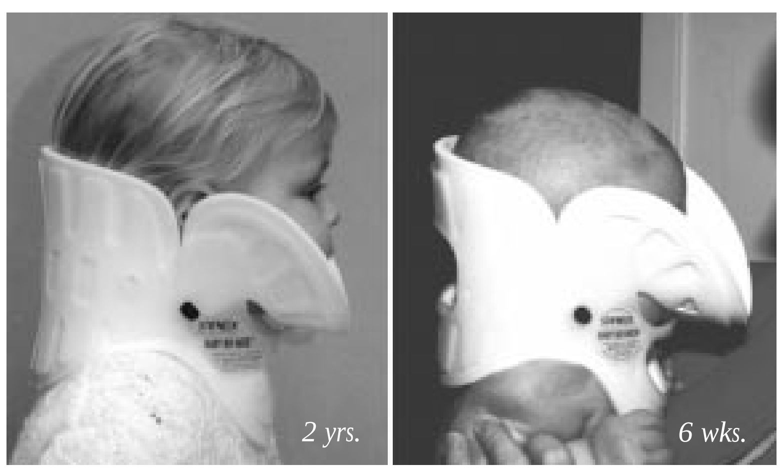


Figure 2.
Comparison of the “Baby No-Neck” cervical spine collar (manufactured by Laerdal Incorporated) on a two year old (left) and a six week old (right). The collars are approximately the same size in both photographs. Photograph by the author.

Uniformly scaling down adult cervical spine collars, keeping them the same shape and relative dimensions, but marketing them for children is a flawed practice. Children's head neck and shoulders exhibit marked variation from individual to individual with respect to age, height and weight categories. The variable relationship of age, size and shape presents difficulties in classifying collar size solely by age even if there were appropriately designed devices.

This study is geared toward visually describing the anthropometry (comparative measurements) of the pediatric HNSC over a range of ages. This is the first detailed study to visually consider the pediatric HNSC anthropometry in approximated neutral position. The goal of this project is to develop visualizations of the proportions and trends with respect to pediatric HNSC growth over a range of ages. These visualizations may be applied to interdisciplinary development of effective immobilization devices for acute care of critically injured children.

Background Issues

Growth rates of different parts of the body vary with age (Huelke) as depicted in Morris' Human Anatomy in the section of the Development of External Body Form (Figure 3). Head circumference increases rapidly in the first postnatal year due to the

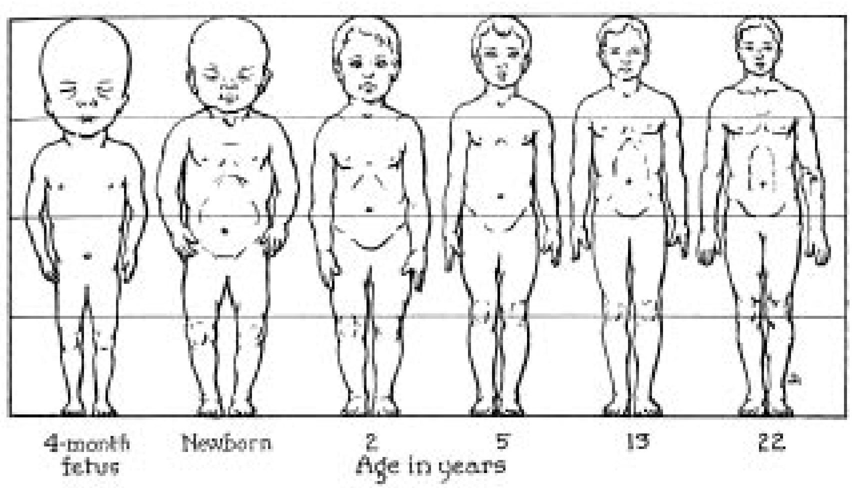


Figure 3. Changes in Body Form and Proportions in the Developmental Period, stature held constant, body delimited in one quarter of stature. Based on the figures from C.H. Stratz. 1909. *Der Körper des Kindes: fur Eltern, Erzieher, Aerzte und Künstler*, 3d ed. Stuttgart:Enke.

rapid growth of the brain as a whole (Huelke). Fifty percent of postnatal head circumference growth occurs by the age of 18 months while 50 percent of the chest circumference growth does not occur until the age of eight years (Herzenberg). From the end of the first year to the twentieth year, there is only a four-inch increase in head circumference (Huelke). Illustrations of the head and body proportions found in many current anatomy books are based on individuals, or an individual radiograph and not on population based data (Figures 4 and 5).

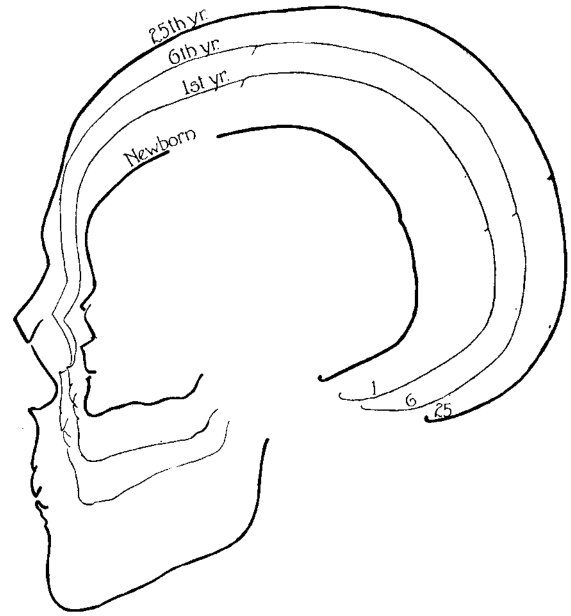


Figure 4. Tracings of median sagittal sections of the skull at different ages, illustrating the rate of growth of the cranium, reproduced from *Morris' Human Anatomy*. Based on the figures of Corrado and Welcker.

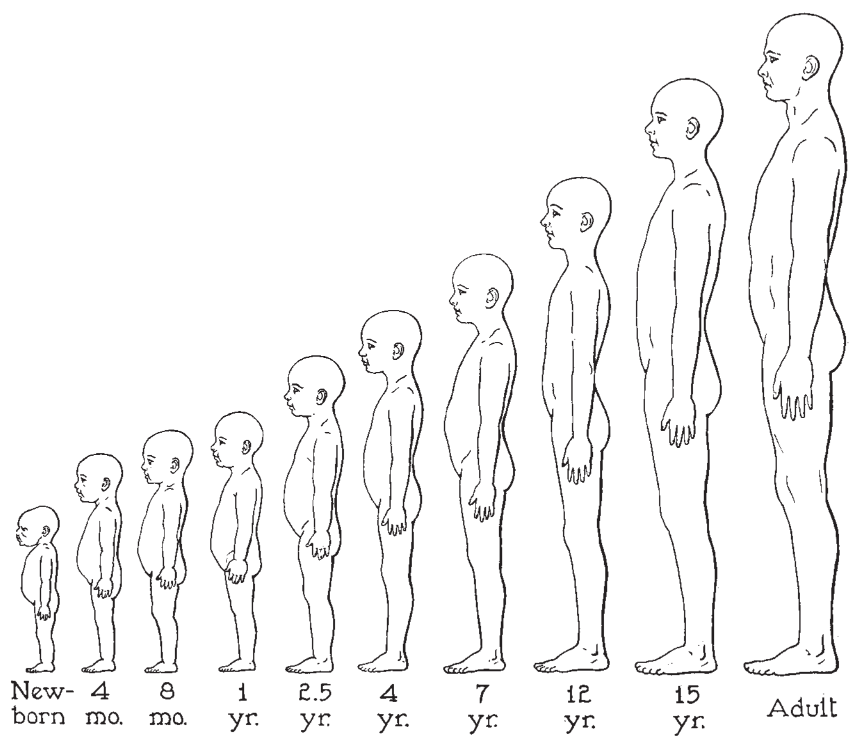


Figure 5. Ten Left Lateral Profiles of the Body Form from Birth to Maturity. Drawn from origional proportions. Based on the figures from G. Schadow. 1882. *Polyclet oder von den Maassen des Menschen nach demGeschlechte und alter mit Angabe der wirklichen Naturgrösse nach demfheinländischen Zollstocke und Metermaase*. 4th ed. Berlin: Wasmuth.

Over 450 years ago, Leonardo daVinci and Albrecht Dürer portrayed visual representations of man's changing proportions. These artists, along with others of their time, developed systems for determining proportions of the human figure. It appears that many of their proportion systems were likely not meant to represent the typical or normal but rather, the ideal. Regardless of the intention, they communicated their observations in a careful, visual and beautiful manner.

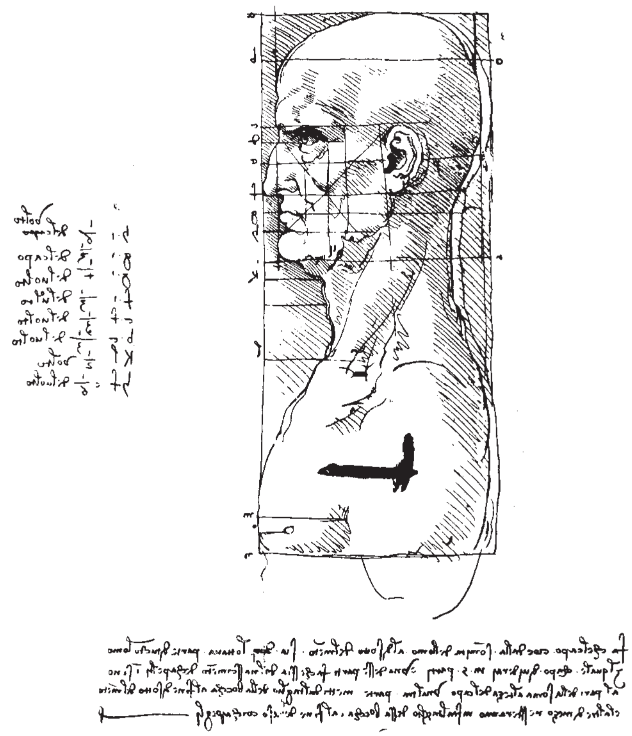


Fig. 2 - « Fa che il capo, cioè dalla sommità dell'uomo al di sotto del mento, sia l'ottava parte di tutto l'uomo; il quale capo dividerai in cinque parti e una di esse parti fa che sia dal nascimento de' capelli in sino al pari della somma altezza del capo; un'altra parte metti dal taglio della bocca al fine di sotto del mento, e l'altra di mezzo resteranno in fra 'l taglio d'essa bocca al fine del viso coi capelli ».

h, i	$\frac{1}{6}$	del volto	*c, f*	$\frac{1}{3}$	del volto
g, i	$\frac{1}{5}$	del capo	*b, c*	$\frac{1}{3}$	del volto
g, i	$\frac{1}{4}$	del volto	*k, l*	$\frac{1}{2}$	volto
f, i	$\frac{1}{3}$	del volto	*h, f* è	$\frac{1}{6}$	del volto

Leonardo: Studio per le proporzioni della testa dell'uomo (R. Galleria dell'Accademia, f. 236 verso, Venezia).

Figure 6. A study of the proportions of the head of man by Leonardo daVinci. Reprinted from Nardecchia, A., ed. 1920. *L'orecchio e il Naso nel Sistema Antropimetrico di Leonardo daVinci.* page 13. Roma: Bilancioni

Detailed background description of the head, neck and shoulder proportions in children is scarce from these sources, however, these artists did visually acknowledge that these pediatric proportions differ from those of adults (Figure 7). In his First Book on Human Proportions, Dürer describes the proportions of a child. In the lateral view as observed in Figure 7, the child's head protrudes farther posteriorly in relation to the shoulders and torso when compared to an adult.

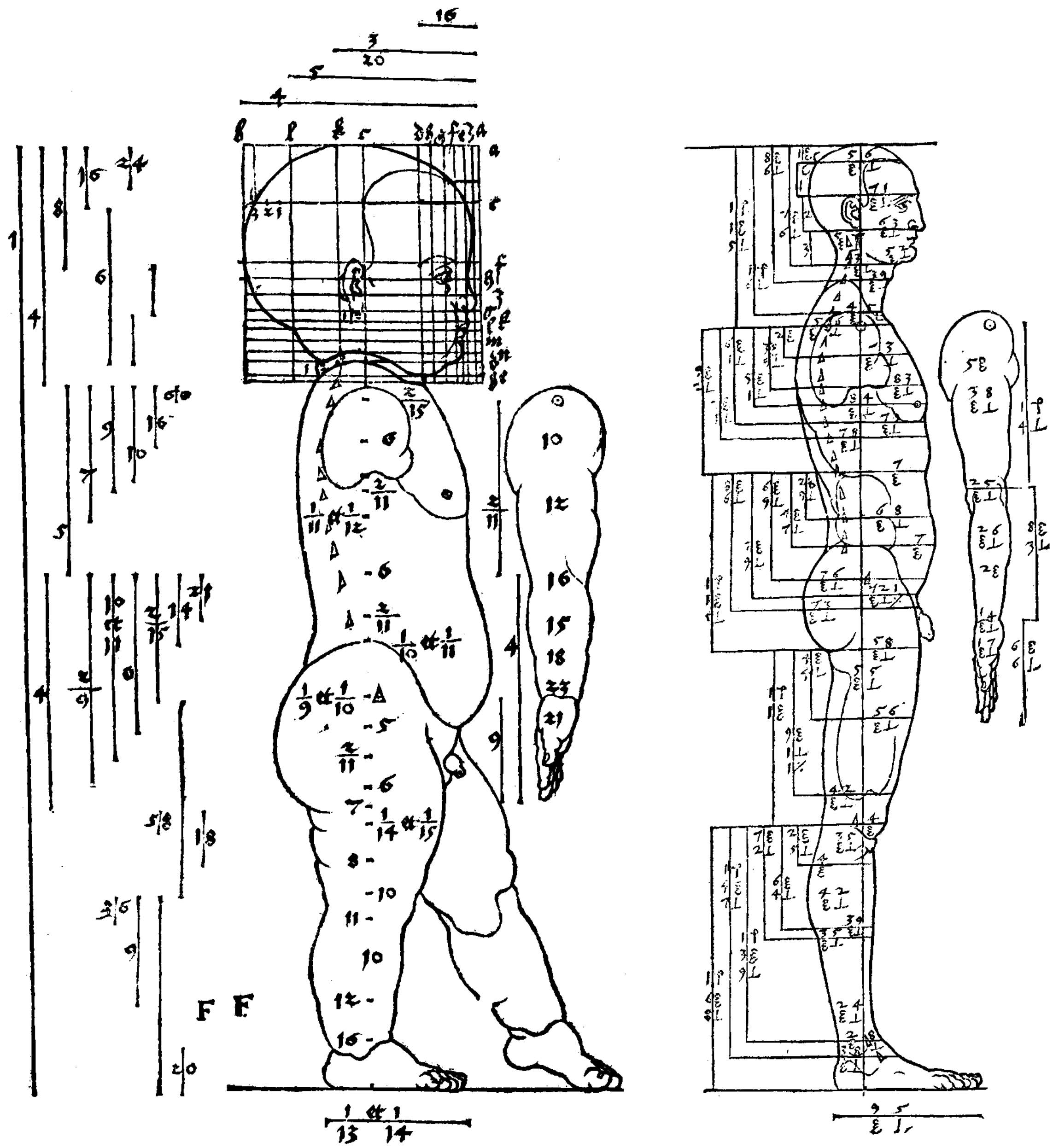


Figure 7. Adapted from illustrations by Albrecht Dürer showing the head and body proportions of a child (left) and an adult (right) from *Les Qvatre Livres d'Albert Dürer…De la proportion des parties & pourtraicts des corps humain.*

Figure 8. (above)
Drawing by Leonardo daVinci. Reprinted from Richter, P. ed. *Notebooks of Leonardo daVinci*. vol 1.

Information on the sources or age of subjects and sample size from which daVinci and Dürer made their observations is lacking. In notes alongside his studies of men, as seen in Figures 6, 8 and 9, daVinci observes the different proportional relationships of the face, head, neck and shoulders. In his writings on the Proportions and Movements of the Human Figure (Richter), daVinci acknowledges, “the difference in the length between the joints in men and boys” and “nature constructs us in the mass which is the home of the intellect (head/braincase), before forming that which contains the vital elements (torso).”

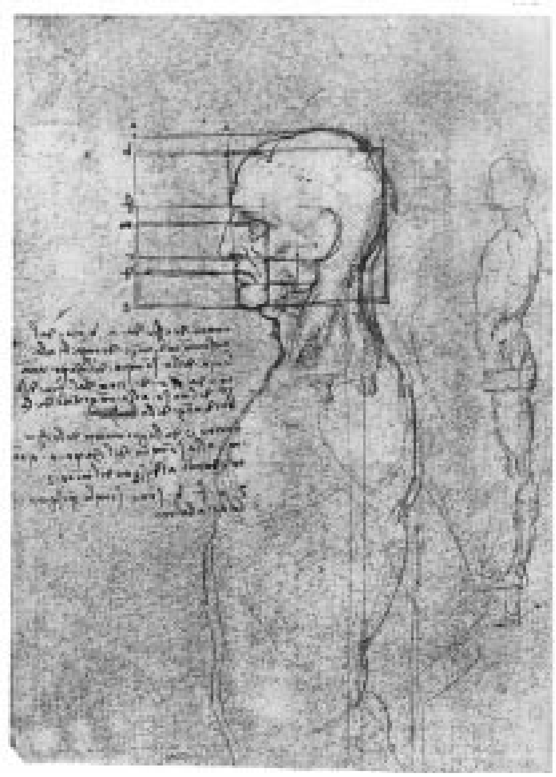


Figure 9. (right)
Drawing by Leonardo daVinci. Reprinted from Richter, P. ed. *Notebooks of Leonardo daVinci*. vol 1.

There has been more recent anthropometric research that provides valuable contributions to the understanding of this anatomy and its proportions in respect to children. In 1975 and 1977, Snyder et al. studied the anthropometry of more that 4,000 children, aged 0-18 years, representative of the US population at that time, to provide data for consumer product design and regulatory considerations (Snyder et al). Much of Snyder's data can be accessed via the AnthroKids website (Figure 10).

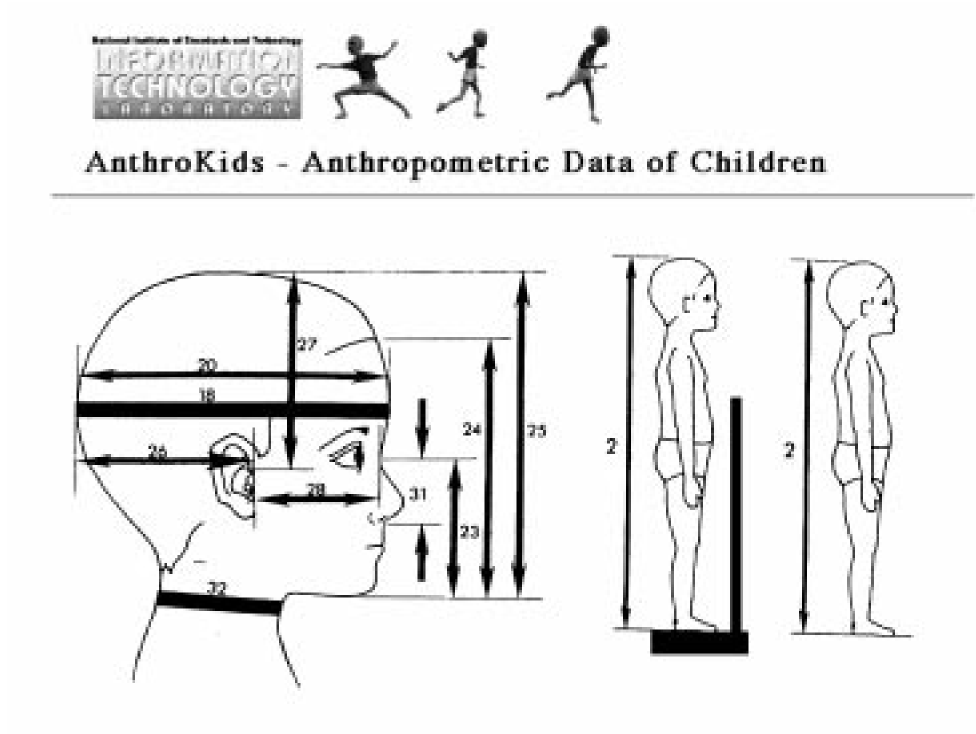


Figure 10. Images adapted from the AnthroKids website. http://ovrt.nist.gov/projects/anthrokids . National Institute of Standards and Technology.

In 1986, Schneider et al. contributed additional anthropometric data on the size and shape of the head and neck for children, aged 0-4 years. This was used by the Consumer Product Safety Commission to determine head and neck entrapment risk. This new study utilizes certain relevant portions from their data to expand the descriptions of the HNSC. Neither of Snyder or Schneider's databases 1) address the relations of the HNSC , 2) consider it as a mobile and dynamic structure or 3) make reference to neutral position or an approximation thereof.

Current Issues

Despite much discussion, and some controversy, there is little clarity about definition of neutral position. Given the flexibility of the neck and the variability of the HNSC relationships it is important to have a constant position for reliable anthropometric measurement and clinical assessment and management. Schriger et al. identifies neutral position as “the normal anatomical position of the head and torso that one assumes when standing looking straight-ahead”. Curran et al. radiographically identifies the neutral position as a Cobb angle (a point of intersection between two lines made on a radiograph) equaling zero degrees. In field emergency situations, neutral position cannot practically be assessed with these methods when the patient cannot be placed in a standing position or examined radiographically. When positioning a child on a backboard (a rigid, flat device upon which, potentially injured children are immobilized), Nypaver and Treolar identify neutral position as that which most closely approximates a child when standing, with preference of gaze directly forward. Lündstrom A. et al. identifies natural head posture as a small range of positions oscillating around the individual’s mean natural head position. The Frankfort, (orbitomeatal), plane is a standard craniometric reference used to define the position of the head but not the neck. It passes through the right and left porion and orbitale as seen in Figure 2 or can be drawn on the profile radiograph or photograph from the superior margin of the acoustic meatus to the orbitale (Stedman). Visual estimation of head orientation is sufficiently reliable (Bass, Lündstrom A., Nypaver). For this study, neutral position was clinically estimated, with the head and neck in neither flexion or extension, when standing and eyes gazing straight ahead for toddlers and children. This same position was maintained with appropriate support for infants.

It is recommended that all trauma patients, including children, be immobilized in the neutral position on flat backboards in cervical collars (American Heart Association). In the emergency setting, cervical spine immobilization aims to protect patients who have bony, ligamentous and/or spinal cord damage from any further injury (Campbell). However, immobilization devices and techniques have been largely derived from studies using adult subjects and may not be applicable to children (Treolar). To achieve spinal neutrality on a flat board, it has been suggested that a child requires elevation of the torso, from the plane of the board (Nypaver), while in contrast, adults require elevation at the occiput (Schriger). Thus theoretically, adult-type immobilization devices may be hazardous for use in young children (Daya and Mariani). Because a child’s head is relatively large compared to his body, positioning the child on a standard backboard may force the neck into flexion. It is suggested that flexion will compromise the spinal canal diameter to a greater degree than extension (Maiman). Flexion may also compromise the patency of the airway in a child more easily that extension.

It has not been clearly established how cervical spine collars should fit an adult or a child. Daya and Mariani describe the collar base as a four-point support structure: two points at trapezius muscles, two points at clavicles anteriorly, with the sternum offering additional fifth support structure. It appears that minimal scientific study had been employed to support this device design. According to Laerdal Incorporated, the manufacturer of the Stifneck Extrication collar, the key dimension on a patient, when determining collar fit, is the vertical distance between the top of the shoulders and the bottom of the chin. This dimension on the collar is represented between a sizing post and the lower edge of rigid plastic encircling band as seen in Figure 11. A collar that is too short may not provide enough support to the HNSC.

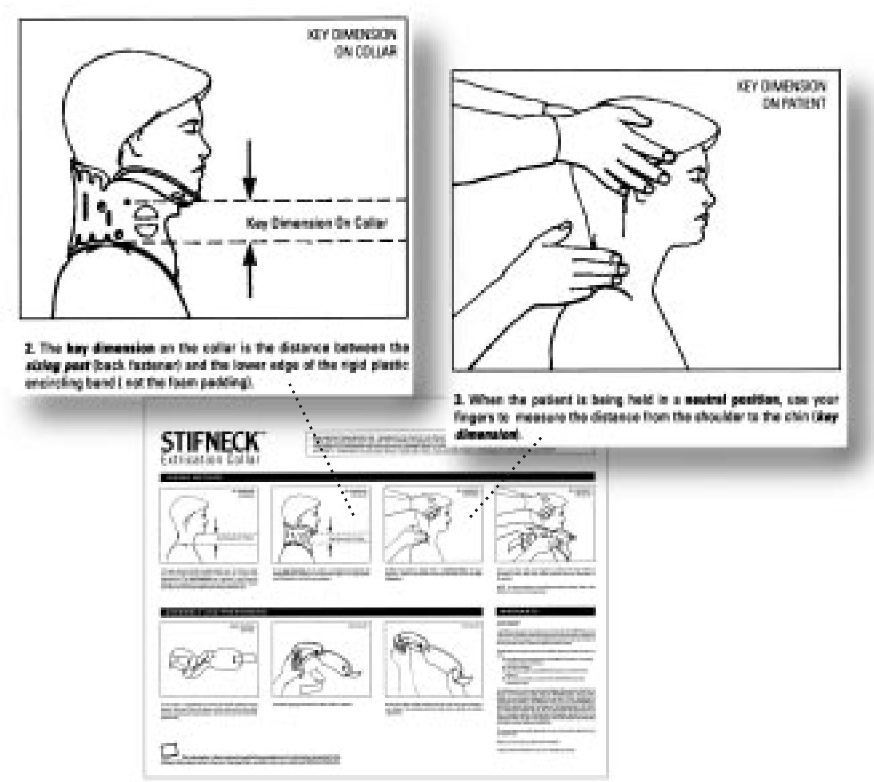


Figure 11. Adapted from the instruction sheet for sizing methods included in the "Baby No Neck" Stifneck cervical spine collar packaging. 1998. Laerdal Medical Corporation.

Mismatch between collar size and shape and the HNSC size and shape may impact on support and immobilization. Insufficient lateral support may allow the head to move from side to side. A collar that is too tall anteriorly under the chin may hyper-extend the head and neck. One that is too tall posteriorly and does not allow room for the child's protruding occiput, will force the head and neck into flexion.

Some of the literature suggests that after the age of eight, the cervical spine assumes a more adult-like functional behavior (Bailey, Hill, Gaufin). Since the more recent literature conflicts with this age assignment (Givens), some older children (to age 14) were included in this study sample. The disproportionately large head, the weak cervical spine musculature and laxity can subject the infant to uncontrolled and passive cervical spine movements (Huelke) which reinforce the importance of effective cervical spine immobilization.

A number of the associated neurologic injuries are suggested to occur or be aggravated during emergency extrication, transport and evaluation of the patient (Podolsky). Williams et al. reported thirteen out of fifty patients with cervical spine fractures were not diagnosed during their initial evaluations. Eighty percent of children with spinal cord injuries were evaluated as normal at the time of initial exam (Dietrich).

Furthermore, it is predicted that there will be an increased need for immobilization. Current data from the National Highway Traffic Safety Administration suggest that although road fatalities are decreasing due to enhanced safety interventions, there is a resultant relative increase in the number of serious injuries (Luchter), including spinal injuries. This trend is being observed in all of the pediatric age groups specifically with respect to cervical spine injury (Givens).

This study identifies nine anthropometric measurements of the HNSC. Tables of numbers as seen in Figure 12, while accurate, do not ease the visualization of the complex relationships contained within data.

The visual challenge was to describe the anthropometrics of the HNSC from limited linear measurements. These data can be drawn to scale with boxes and lines (Figure 13a). Within these constructed geometric box diagrams, a lateral silhouette of the head can be approximated (Figure 13b).

study#	age$_{years}$	weight$_{kg}$	headCirc.	ineA$_{cm}$	ineB$_{cm}$	ineC$_{cm}$	ineD$_{cm}$	ineE$_{cm}$
29	6.0	22.4	55.0	10.0	8.0	10.0	3.0	19.0
30	5.7	20.3	52.5	8.5	8.5	7.0	3.5	18.0
31	6.7	31.9	53.0	8.0	9.5	7.5	2.5	15.0
32	3.0	25.8	53.0	10.0	10.0	7.0	2.0	19.0
33	5.4	21.1	52.0	10.0	9.0	6.0	4.0	17.0
34	2.4	11.7	49.5	10.5	8.5	7.0	4.0	14.5
35	7.4	49.6	51.8	8.0	8.5	6.0	3.5	15.5
36	7.4	47.5	53.0	8.5	9.0	5.0	5.5	16.0
37	8.0	53.5	50.5	10.0	11.0	8.0	4.5	15.0
38	5.0	17.3	54.0	9.0	10.0	6.0	3.5	17.0
39	0.1	4.1	40.0	10.0	5.0	4.0	6.0	14.0
40	9.2	54.4	59.5	11.0	11.0	8.5	2.0	17.5
41	12.9	40.7	56.0	9.0	12.0	6.5	3.0	16.0
42	0.7	8.5	44.0	6.0	5.0	3.0	3.0	12.0
43	4.0	15.4	49.5	10.0	7.5	6.0	4.5	16.0
44	2.0	13.2	48.0	9.0	8.5	4.5	3.5	15.0
45	8.9	34.0	56.5	9.0	11.0	6.5	2.5	16.0
46	12.1	47.2	56.0	10.5	12.0	5.0	1.0	17.0
47	4.4	20.8	56.0	11.0	9.5	6.5	4.0	17.0
48	4.0	16.1	53.5	10.0	9.0	5.5	5.0	16.0

Figure 12. Sample of data from Excel Spreadsheet to demonstrate the numerical data without visual depiction.

An additional visual challenge was to describe the change in the size and shape of the HNSC with age, height and weight. For this, the proportional boxes provided a method to compare groups of individual heads with one another (Figure 21). Mean (average) HNSC box diagrams can be made from certain groups of individuals and compared between age, height or weight groups to observe relationships. The size of the pediatric HNSC was also visually compared to the size of collars by photographing children in neutral position without the collar and then with the collar.

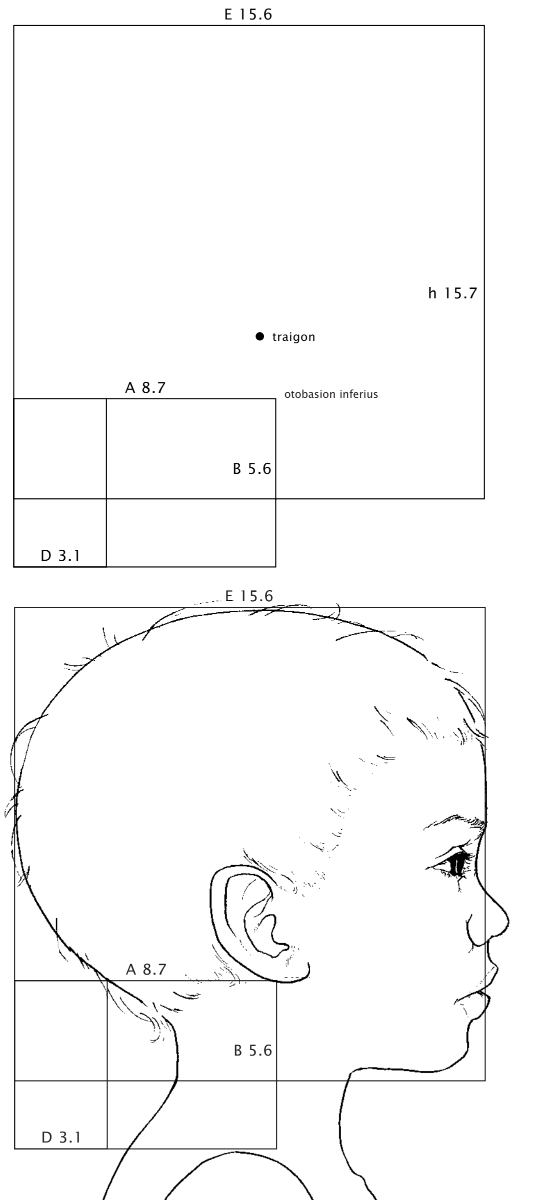


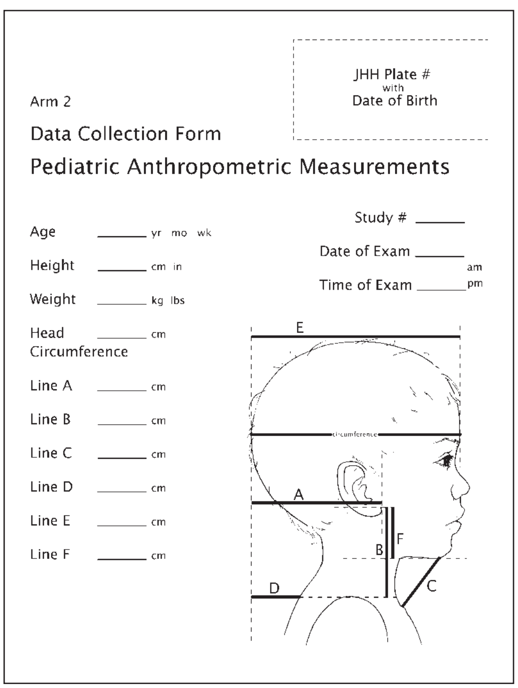
Figure 13. Example of HNSC box diagram based on averages. This is the average HNSC based on all of the data.
a. (top) HNSC represented with boxes only
b. (bottom) HNSC with drawn lateral silhouette of head

Methods

Anthropometric Data Collection

In order to study the relationship between age, height and anthropometric measurements, data were collected using cross-sectional-design study. After obtaining Institutional Review Board (IRB) permission, one hundred and twenty eight children seeking medical care at the Johns Hopkins Hospital Pediatric Emergency Department or at the Harriet Lane Pediatric Clinic were enrolled in this study. Written informed consent was obtained from family members or guardians at the time of the study assessment. Exclusion criteria consisted of 1) age of 15 years or more at time of presentation, 2) any severe injury or trauma in which data collection would impede immediate medical care and 3) patients without a parent or legal guardian or who were unable to give proper consent and 40 patients with obvious spinal and cranial deformities.

A single trained data collector gathered anthropometric data. Nine specific anatomic sites on the HNSC were measured with the child in approximated neutral position (Figure 15). Older cognitive children were instructed to stand "straight like a soldier" and "eyes straight ahead". Infants were supported in a similar position and measured. Neutral position was visually estimated as neither flexion nor extension of the HNSC. The linear and head circumference data were gathered manually using a tape measure to the nearest half-centimeter. Stature was measured to the nearest millimeter with the participant standing in approximated neutral position. Weight was measured to the nearest tenth of a kilogram with the participant standing on a clinical scale clothed but without shoes. For infants, weight was measured to the nearest tenth of a kilogram on a standard infant scale. The measurements were recorded on the data collection form for each participant as seen in Figure 14.


JHH Plate #
with
Date of Birth

Arm 2

Data Collection Form

Pediatric Anthropometric Measurements

Study # ______

Date of Exam ______

Time of Exam ______ am pm

Age ______ yr mo wk

Height ______ cm in

Weight ______ kg lbs

Head Circumference ______ cm

Line A ______ cm

Line B ______ cm

Line C ______ cm

Line D ______ cm

Line E ______ cm

Line F ______ cm

Figure 14. Sample data collection form used for gathering anthropometric measurements

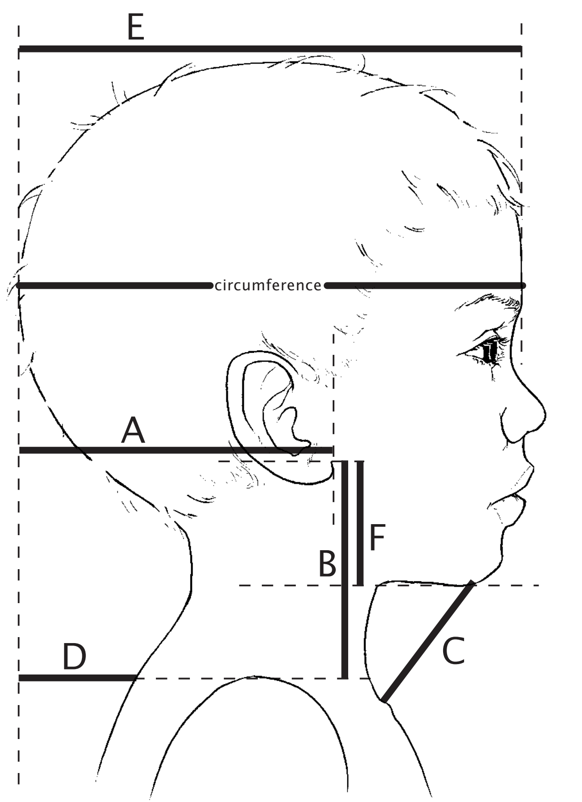
Measurements Collected

age (in years)	
weight (in kilograms)	
height	
head circumference	
line E	head length= glabella (gl) to occipital point (op)
line A	occipital point (op) to otobasion inferius (obi)
line B	shoulder crest (sc) to otobasion inferius (obi)
line C	gonion (gn) to suprasternale (ss)
line D	occipital point (op) to shoulder crest (sc)
line F*	gonion (gn) to otobasion inferius (obi)

note: measurements are in centmeters unless otherwise noted

* line F was added midway throught the process of data collection however, not utilized in the statistical analysis due to insufficient amount of measurements

Figure 15. Measurements collected in this study:
a. table (above)
b. illustration (below).
Solid lines indicate the measured anthropometric dimensions on the pediatric HNSC.



Anthropometric Data Handling

The data was entered from the data sheets to an Excel spreadsheet in (Microsoft Excel 98®, Macintosh) and analyzed using SAS version 6.12® (SAS Corporation, NC). In order to identify any outliers (an observation that differs so widely from all others in a set) due to data entry error, frequency distribution histograms were generated. To insure the data followed a normal distribution, a Gaussian curve of the data was created and any skewed distribution was noted. Univariate frequency tables for each variable was generated. Bivariate frequency tables were created for age by height, height by line A, height by line B, height by line C, height by line D, height by line E, and height by head circumference as well as age by line A, age by line B, age by line C, age by line D, age by line E, and age by head circumference.

A graphical model, called a scatter plot, was used to display the distribution of two variables in relation to one another (Figure 15). Using the method of least squares, a line of best fit was produced and superimposed on the scatter plot.

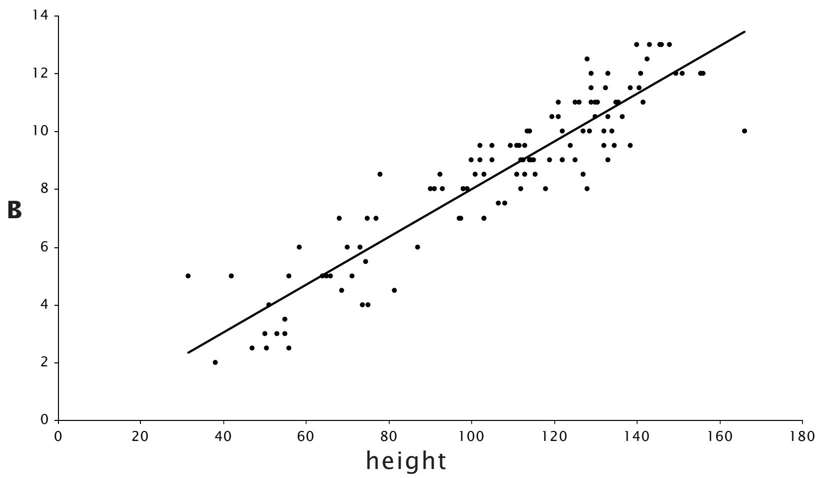


Figure 16. A scatterplot created in Microsoft Excel 98®, displaying the individual data points of two variables (in this case height to line B) in relation to one another.

The slope (the rate of change between two points in a line) was calculated by taking two data points on the line [for example, (x^1,y^1) and (x^2,y^2)] and using the following formula: $m=(y^2-y^1)/(x^2-x^1)$. The y-intercept (b), the point at which the line crosses the y-axis of a graph, of this line was also determined by SAS. Since the equation of any straight line is $y=mx+b$, the equation for each superimposed line was determined.

The numerical change in the HNSC was analyzed to demonstrate the association between measurements and stability of the data. Thus, in order to measure the degree to which two variables have a linear relationship, the correlation coefficients (r) for age and height, height and line A, height and line B, height and line C, height and line D, height and line E, and , height and head circumference were calculated. The value of r can range from +1 to -1. When r=+1 there is a perfect positive linear relationship in which one variable varies directly with the second. When r=-1 there is a perfect negative linear relationship in which one variables varies directly with the second. If r=0 then no relation may exist.

Due to the fact that normal pediatric growth is not a direct linear relationship throughout time, various transformations (such as logarithmic, exponential, and 2nd power) were tested to determine the equation for the line of best fit.

The study population was then stratified into 20-cm height groups as seen in Figure 16.

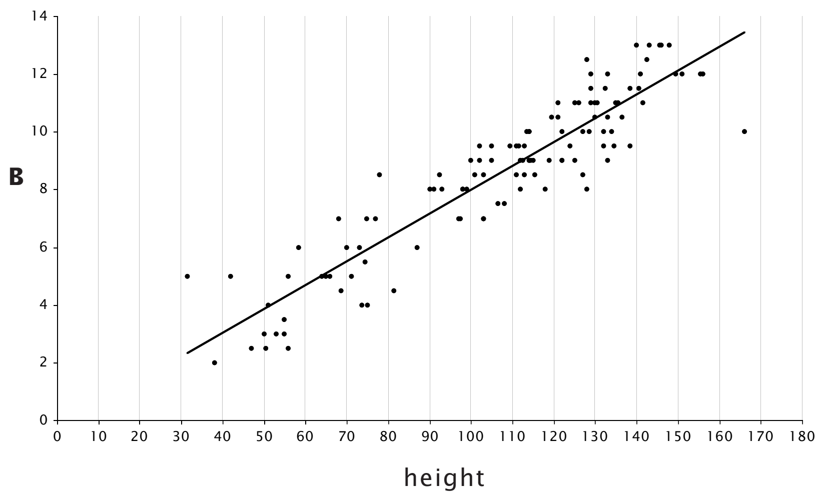


Figure 17. On this scatter plot, height is divided into groupings based on 20-cm increments.

Average lengths of line A-E and average head circumference for each strata were calculated and graphed on a scatter plot as seen in Figure 17. Finally, the study population was re-stratified according to one-year age groups and re-analyzed.

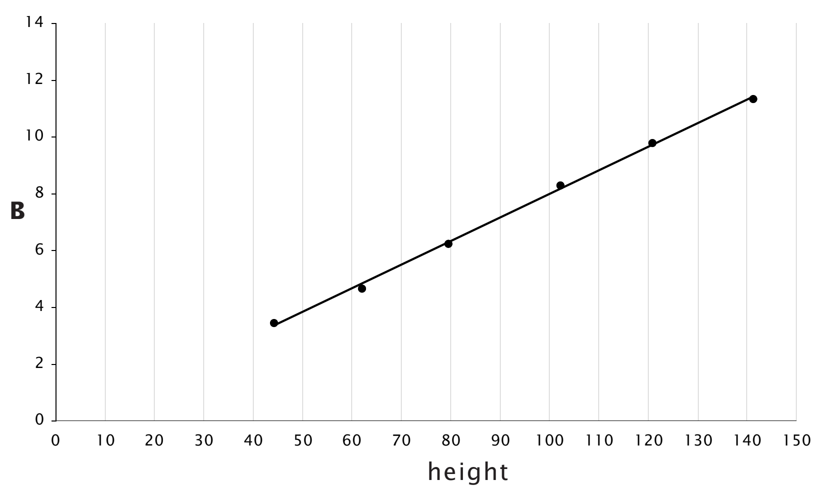


Figure 18. Each strata (20 cm grouping) is averaged and the line of best fit and equation of the line is determined.

This HNSC data was expanded with relevant overlapping portions of anthropometric data recorded by Snyder et al., Schneider et al. The datasets of Snyder and Schneider were not directly merged with the dataset of this study, but rather used as a baseline for comparison of measurement and proportions. Snyder data were obtained from “Anthropometry of Infants, Children and Youths to Age 18 for Product Design” via the AnthroKids website and imported into an Excel spreadsheet. Schneider data were obtained from “Size and Shape of the Head and Neck from Birth to Four Years”, the final report to The Consumer Product Safety Commission. For consistency, data from Schneider were used for ages 0-2 years and data from Snyder was used for ages 2-10 years. Both Schneider and Snyder organize their data by age and somewhat different age groupings (Figure 19).

Schneider	Snyder
months 0-3	0-2 months
4-6	3-5
7-9	6-8
10-12	9-11
13-18	12-15
19-24	16-19
	20-23
25-30	2.0-3.5 years
31-36	
37-42	
43-48	3.5-4.5
	4.5-5.5
	5.5-6.5
	6.5-7.5
	7.5-8.5
	8.5-9.5
	8.5-9.5
	9.5-10.5
	10.5-11.5
	11.5-12.5
	12.5-13.5

Figure 19.
Comparing age groups Snyder and Schneider used to average their data. The darkened ages were used to expand the data for the corresponding age group in this study.

Visualizing the HNSC

Some of data points taken in this study overlap with those of Snyder and Schneider (Figure 20). These additional aggregate anthropometric data from Snyder and Schneider allowed the reconstruction of the basic proportions of the child’s head, neck and shoulders using boxes drawn to scale (HNSC box diagrams). These HNSC boxes were constructed in Quark Xpress 4.0® and Adobe Illustrator7.0®. Additional measurements for each observation were extrapolated using a proportion calculation. The appropriate Snyder(Sny) or Schneider(Sch) age group data was used according to the corresponding age group of the individual observation. Since line E was highly correlated to line B (neck length) then, head height (h), vertex to shoulder crest (v to sc), vertex to traigon (v to t) could be proportionately associated with line E.

Head height was calculated using the following formula:

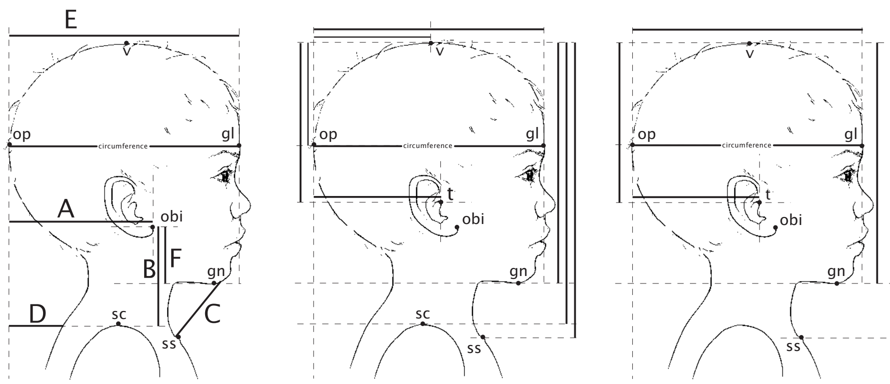
Line E / x = Sny or Sch E / Sny or Sch h

Vertex to traigon distance was calculated using:

Line E / x = Sny or Sch E / Sny or Sch v to t

Vertex to shoulder crest distance was calculated using (for 0-2 years only):

Line E / x = Sch E / Sch v to sc

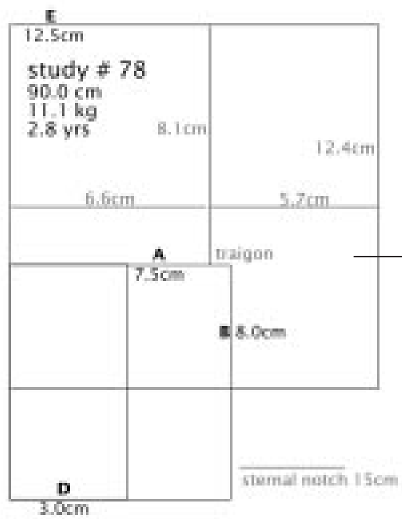


This study (0-14 years)	Schneider (0-2 years)	Snyder (2-14 years)
height	height	height
weight (kg)	weight (kg)	weight (kg)
age (years)	age (years)	age (years)
head circumference (HC)	head circumference (hc)	head circumference (hc)
-	head height = v to gn vertex to gonion	head height = v to gn vertex to gonion
head length = line E glabella to occipital point	head length (e) = gl to op glabella to occipital point	head length (e) = gl to op glabella to occipital point
-	t to op traigon to occipital point	t to op traigon to occipital point
-	v to t vertex to traigon	v to t vertex to traigon
-	v to ss vertex to suprasternale	v to ss vertex to suprasternale
-	v to hc vertex to head circumference	-
-	v to sc vertex to shoulder crest	-
-	op to hb occipital point to head breadth	-
line A = op to obi occipital point to otobasion inf.	-	-
line B = sc to obi shoulder crest to otobasion inf.	-	-
line C = gn to ss gonion to suprasternale	-	-
line D = op to sc occipital point to shoulder crest	-	-
*line F= gn to obi gonion to otobasion inf.	-	-

Figure 20. Schneider and Snyder measurements taken compared to those of this study
*line F was added midway thought the process of data collection however,
not utilized in the statistical analysis due to insufficient amount of measurements.

Visualizing change in the HNSC

Initially, the growth of the HNSC was observed by comparing a layout of “individual HNSC” diagrams (Figure 21a). These “Individual HNSC” box diagrams were organized in ascending chronological order and called a “Combined HNSC” box diagram plates (Figure 21b).



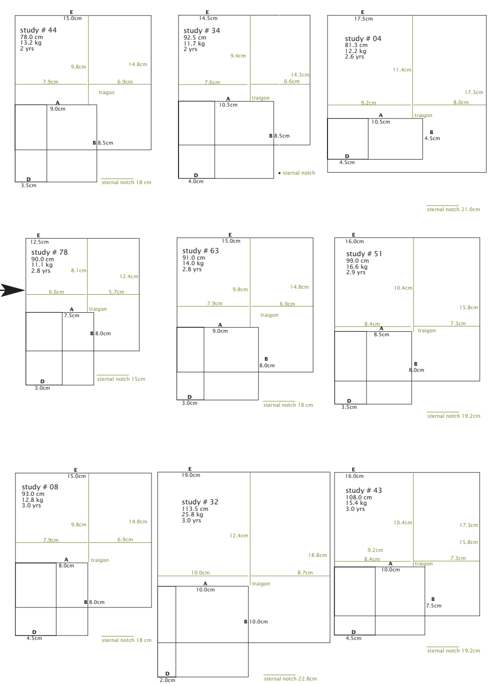


Figure 21. HNSC box diagrams
a. “Individual HNSC” box diagram (right)
b. “Combined HNSC” box diagram plate (left).

Ultimately, the changing proportions in HNSC were visualized using the HNSC diagrams sorted based on height, using the results of the statistical analysis. The scatter plot, used to display the distribution of two variables in relation to one another. Once it was determined that an observation HNSC as seen in Figure 21a, could be represented using the limited original measurements, it would be possible to represent a fictional, predicted HNSC made from average values for each measurement. From these average values, a HNSC diagram could be generated to represent the predicted size and shape of a child’s HNSC at a certain height. To review, the predicted average values were created by:

1) stratifying the study population into groups based on height
2) averaging lengths of each of six variable groups (lines A-E and HC) and
3) from these average variable values, a scatter plot was created and a line of best fit was superimposed for height versus variable

According to the equation of the line of best fit shown in Figure 23, the value of a variable (A-E or HC) was determined for chosen heights (35-145 cm, at 10 cm increments) from the equation for the line of best fit (y=mx+b). Head height, shoulder to otobasion distance and traigon to vertex distance were calculated for these average heads using Schneider and Snyder's data in the same way these measurements were used to create the additional measurements for the individual heads.

At each 10 cm height increment, the predicted lengths of lines A-E and HC were used to generate a predicted HNSC box diagram. Initially the HNSC box diagrams for predicted averages were superimposed over one another to depict the growth trends shown in Figure 28a and b. In Figure 28c the HNSC box diagrams for predicted averages were reduced and placed side by side on the same page, not superimposed. Another method to compare the change in the HNSC was created by combining on the same plate, the "55 cm HNSC diagram" (representing a baby) with the "95 HNSC diagram", and also the "135 HNSC diagram" (representing of an older child) as seen in Figure 29.

To represent the growth in the HNSC over time, the HNSC box diagrams were then imported into Macromedia Director®, ordered sequentially by increasing height, and animated. This animation made it appear as if the HNSC was actually growing.

Cervical spine collars size versus HNSC size was visualized by taking photographs of children at ages 6 weeks, 2 years, 4 years and 6 years in cervical spine collars (Figure 24).

Results

Our mean age was 4.9 years with a minimum of 7 days and a maximum of 14.8 years. Our average height was 107.1 cm (3.5 ft) with a minimum of 31.5 cm (1.0 ft) and a maximum of 166.0 cm (5.4 ft). Our average weight was 22.6 kg with a minimum of 2.3 kg and a maximum of 108.6 kg (Table 1). A complete table of the data can be found in the appendix (Table 4).

Table 1. Mean of *all* data with standard deviation (SD)

measurement	mean (SD)
age yrs	4.9 (3.6)
weight kg	22.6 (16)
height cm	107.1 (30.4)
head circ. cm	50.3 (5.5)
line E cm	15.6 (1.9)
line A cm	8.7 (1.3)
line B cm	8.3 (2.8)
line C cm	5.6 (2.0)
line D cm	3.1 (1.1)

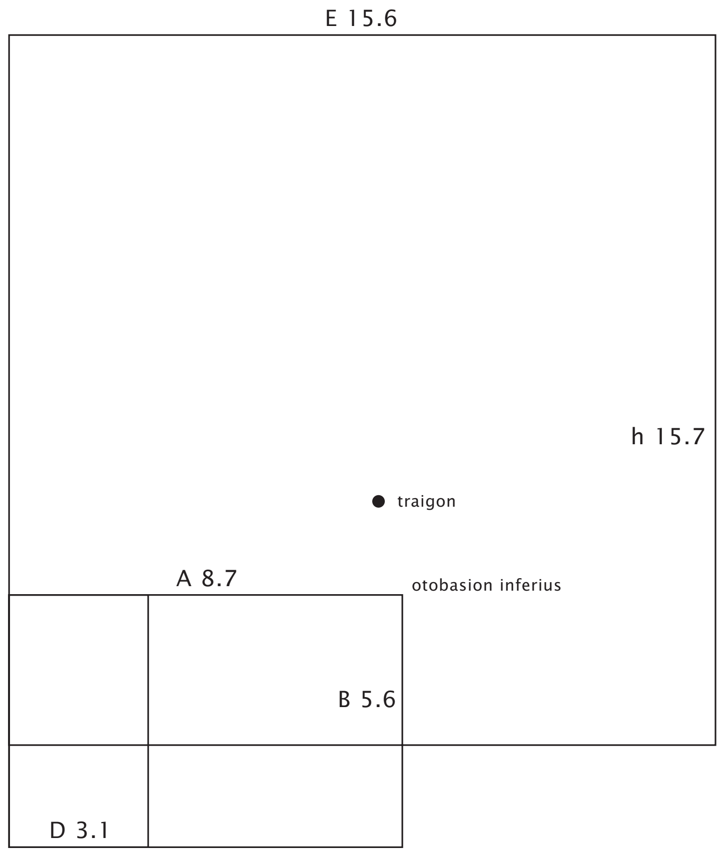


Figure 22. Mean of *all* data HNSC box diagram (reduced sixty percent)

Height (r^2 :0.926) is a better predictor of age than weight (r^2 :0.833). Compared with age and weight, height has the highest correlation (r^2 :0.92) to neck height (line B). The r^2 values for each variable as correlated to age, weight or height are found in Table 2.

Table 2. Variable A-E and head circumference as related to age, weight or height.

measurement	correlation coefficient r^2
age	
height	0.92
weight	0.83
head circ.	0.79
line E	0.59
line A	0.35
line B	0.86
line C	0.75
line D	-0.26
height	
age	0.92
head circ.	0.88
line E	0.63
line A	0.38
line B	0.92
line C	0.78
line D	-0.31
weight	
age	0.83
head circ.	0.71
line E	0.51
line A	0.41
line B	0.69
line C	0.69
line D	-0.22

Table 3. Average measurements used for the construction of the predicted HNSC based on height. The Snyder or Schneider age groupings used for each HNSC diagram is indicated. Also, shaded columns represent additional variable values calculated with Snyder or Schneider data.

Age group used	Height	Head circ	line A	line B	line C	line D	line E	S/S E	S/S h	calculated h	S/S t-v	calc. t-v	Sch s-v	calc. s-v
Schneider 0-3	35	36.4	7.2	2.6	2.1	4.1	12.9	13.9	13.6	12.6	9.6	8.9	14.9	13.8
Schneider 0-3	45	39.3	7.5	3.4	2.6	3.9	13.2	13.9	13.6	12.9	9.6	9.1	14.9	14.1
Schneider 0-3	55	41.8	7.9	4.2	3.1	3.8	13.7	13.9	13.6	13.4	9.6	9.5	15.3	13.6
Schneider 4-6	65	44.0	8.1	5.1	3.6	3.6	14.1	15.4	14.5	13.3	10.6	9.7	15.3	14.0
Schneider 10-12	75	46.0	8.3	5.9	4.1	3.5	14.5	16.3	15.8	14.1	11.3	10.1	17.7	15.7
Schneider 19-24	85	47.8	8.5	6.7	4.6	3.3	14.9	17.2	16.8	14.6	11.5	10.0	18.7	16.2
Snyder 2.0-3.5	95	49.4	8.7	7.6	5.1	3.2	15.3	17.5	17.3	15.1	11.4	10.0		
Snyder 4.5-5.5	105	51.0	8.9	8.4	5.6	3.1	15.7	18.1	17.9	15.5	11.6	10.1		
Snyder 5.5-6.5	115	53.0	9.0	9.2	6.1	2.9	16.1	18.2	18.4	16.3	11.6	10.2		
Snyder 7.5-8.5	125	53.8	9.1	10.1	6.6	2.8	16.5	18.6	18.8	16.7	11.7	10.4		
Snyder 8.5-9.5	135	55.1	9.3	10.9	7.1	2.6	16.9	18.6	19.0	17.3	11.9	10.8		
Snyder 10.5-11.5	145	56.3	9.4	11.7	7.6	2.5	17.3	18.6	19.9	18.5	12.2	11.3		

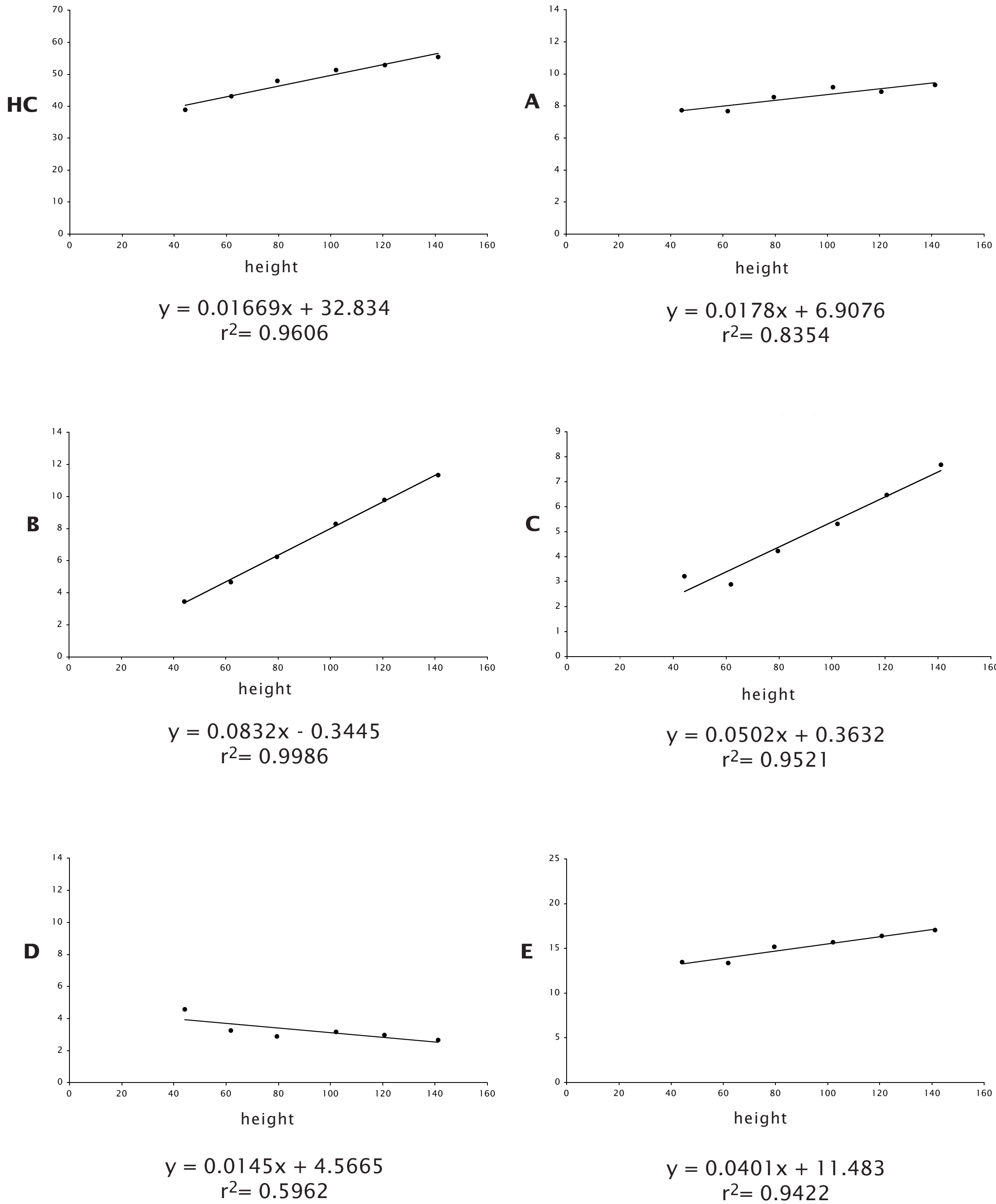


Figure 23. Scatter plots for averaged 20 cm strata with each variable A-E and HC. Each dot represents the average of the strata. The equations for the superimposed lines of best fit are listed below each graph. These equations determined the predicted value of a variable A-E and HC at the chosen increments 35, 45, 55, 65, 75, 85, 95, 105, 115, 125, 135 and 145 cm.

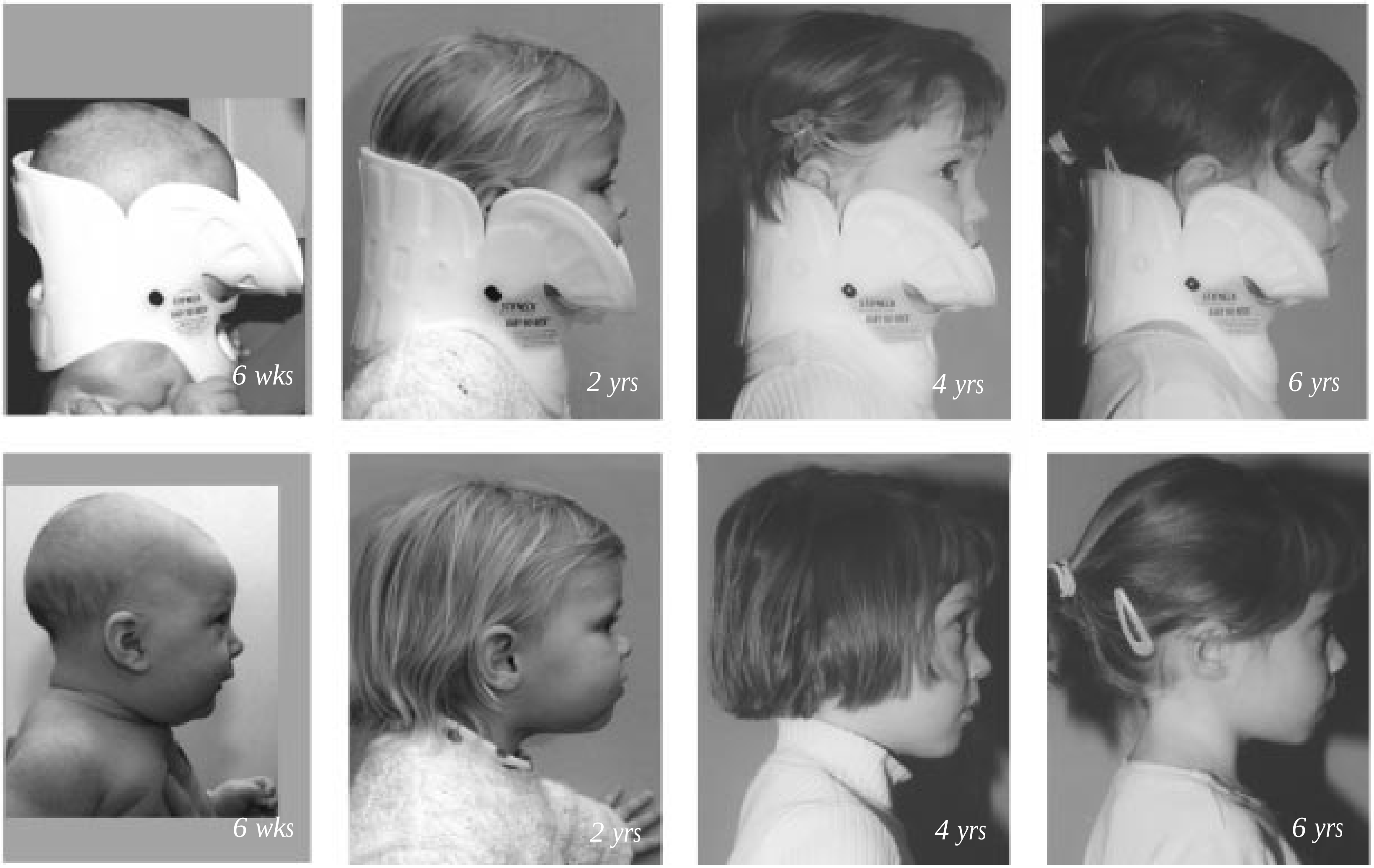


Figure 24. (Top) Children in approximated neutral position to compare (bottom) wearing "Baby No-Neck" cervical spine immobilization collar (in descending order) 6 week old, 2 year old, 4 year old, 6 year old. Manufactured by Laerdal Medical Inc.

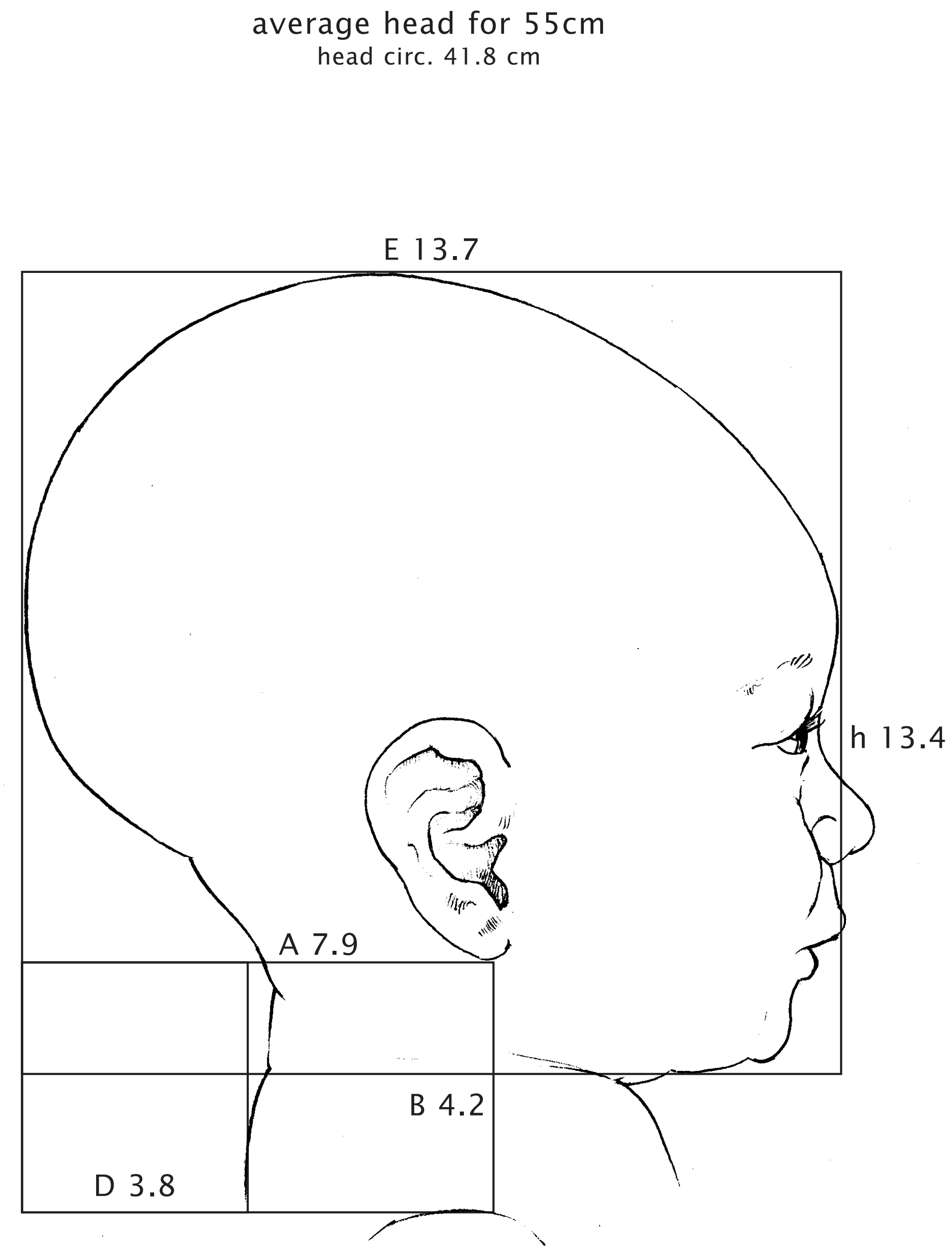


Figure 25. 55cm predicted average HNSC box diagram with head superimposed reduced eighty percent

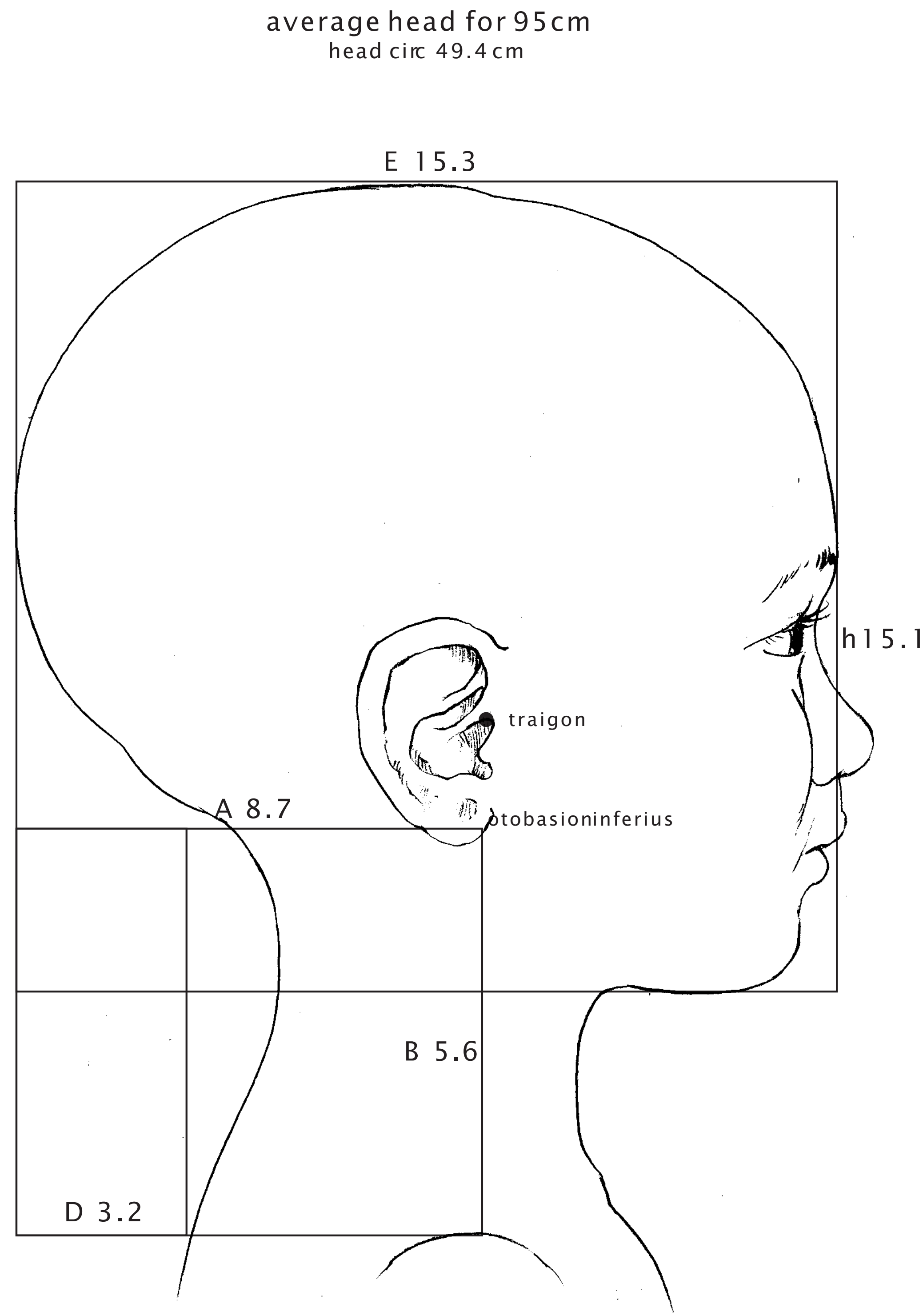


Figure 26. 55cm predicted average HNSC box diagram
reduced eighty percent

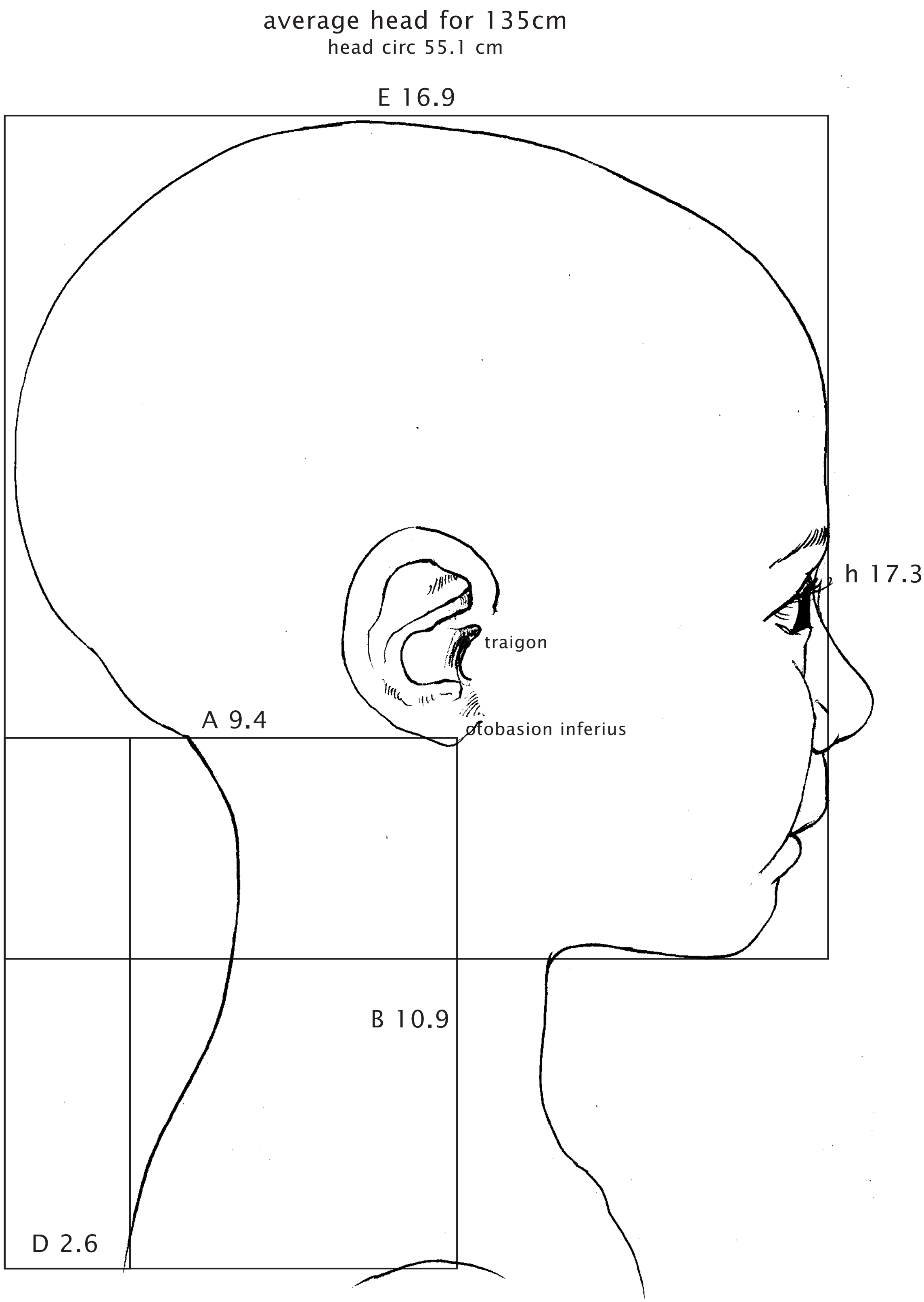


Figure 27. 135 cm predicted average HNSC box diagram
reduced eighty percent

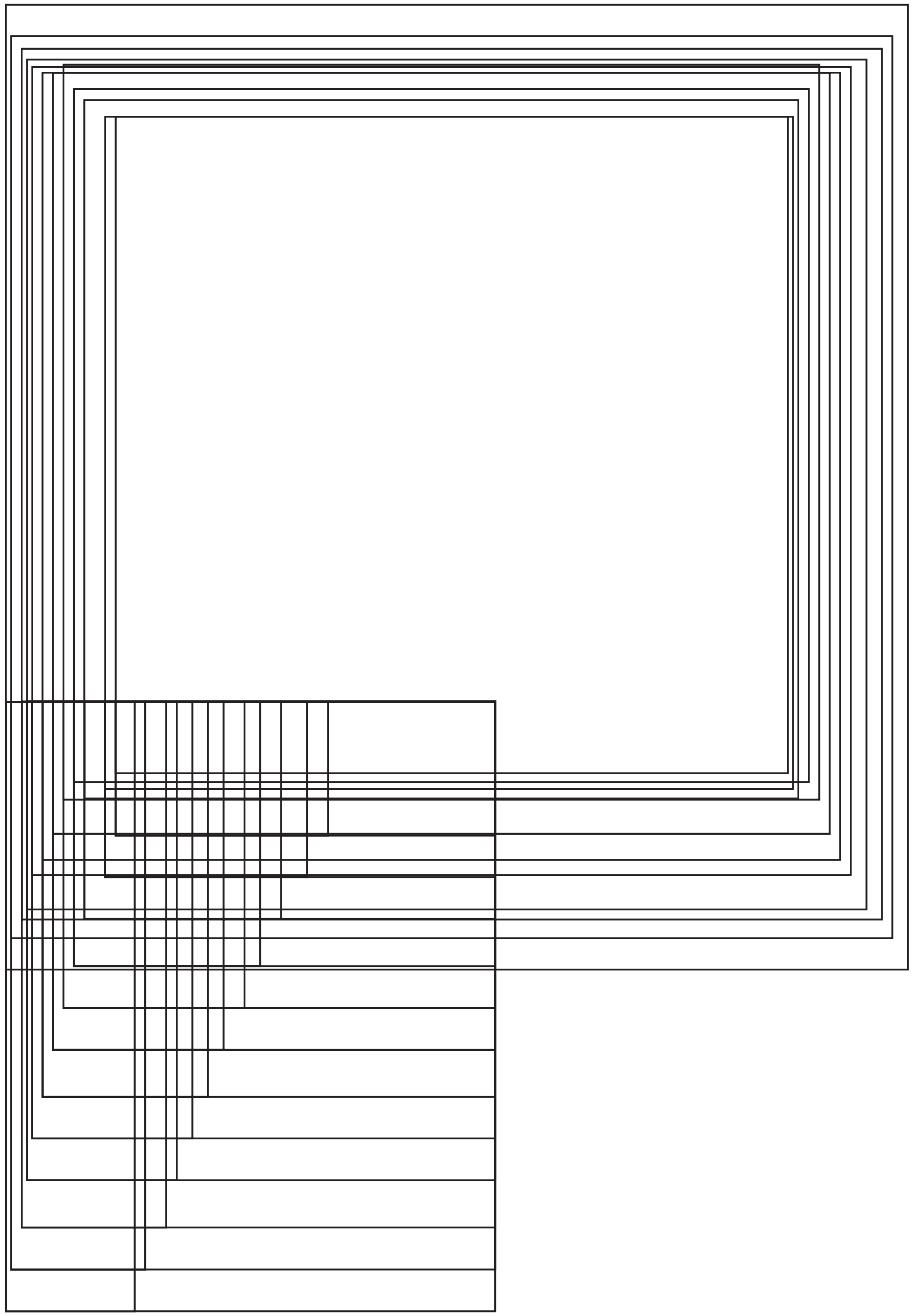


Figure 28a. Superimposed HNSC box diagrams of the predicted averages based on height (35-145 cm)
Aligned at the otobasion inferius
Reduced eighty percent

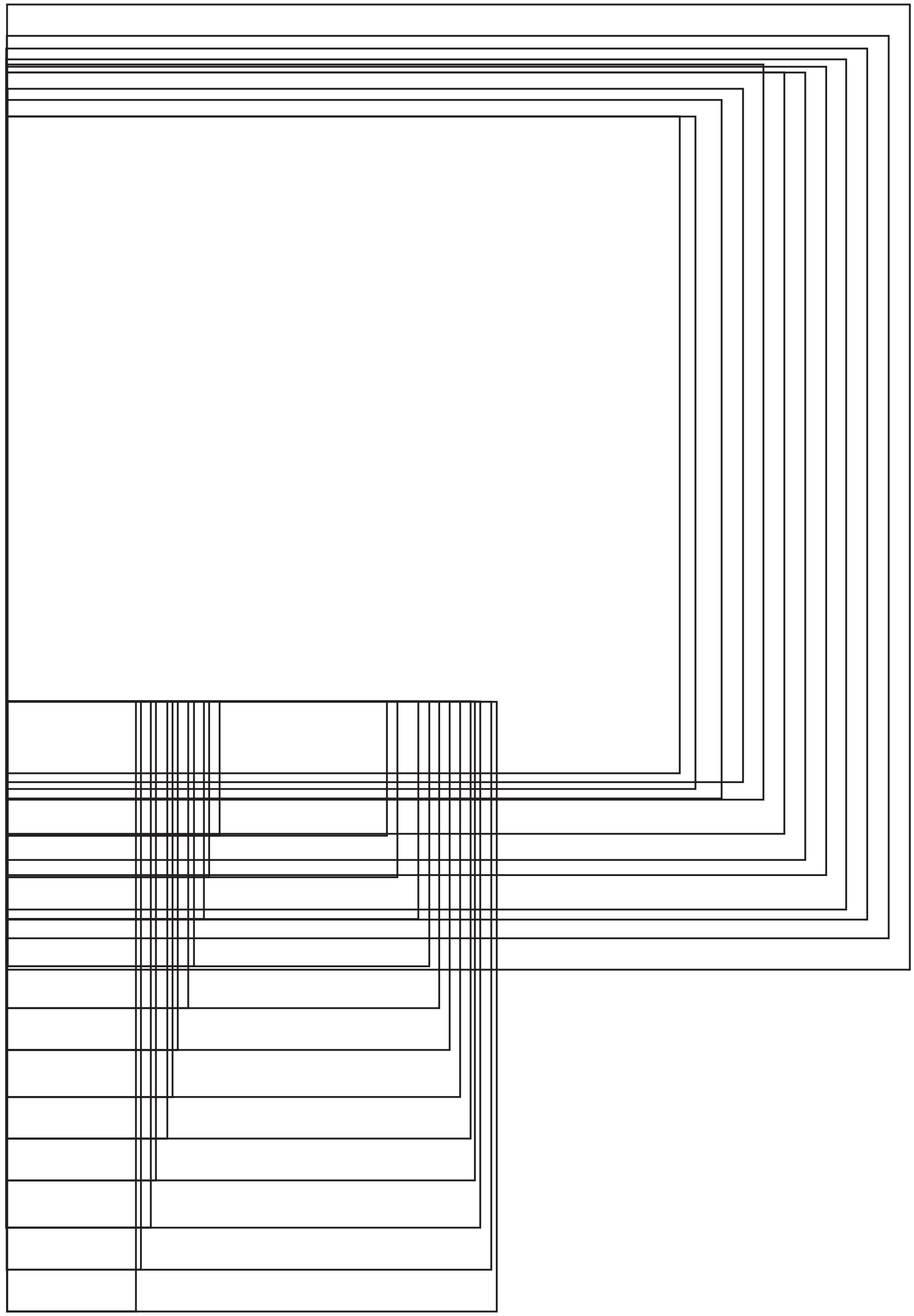


Figure 28b. Superimposed HNSC box diagrams of the predicted averages based on height (35-145 cm)
Aligned at the occipital line and the otobasion inferius level
Reduced eighty percent

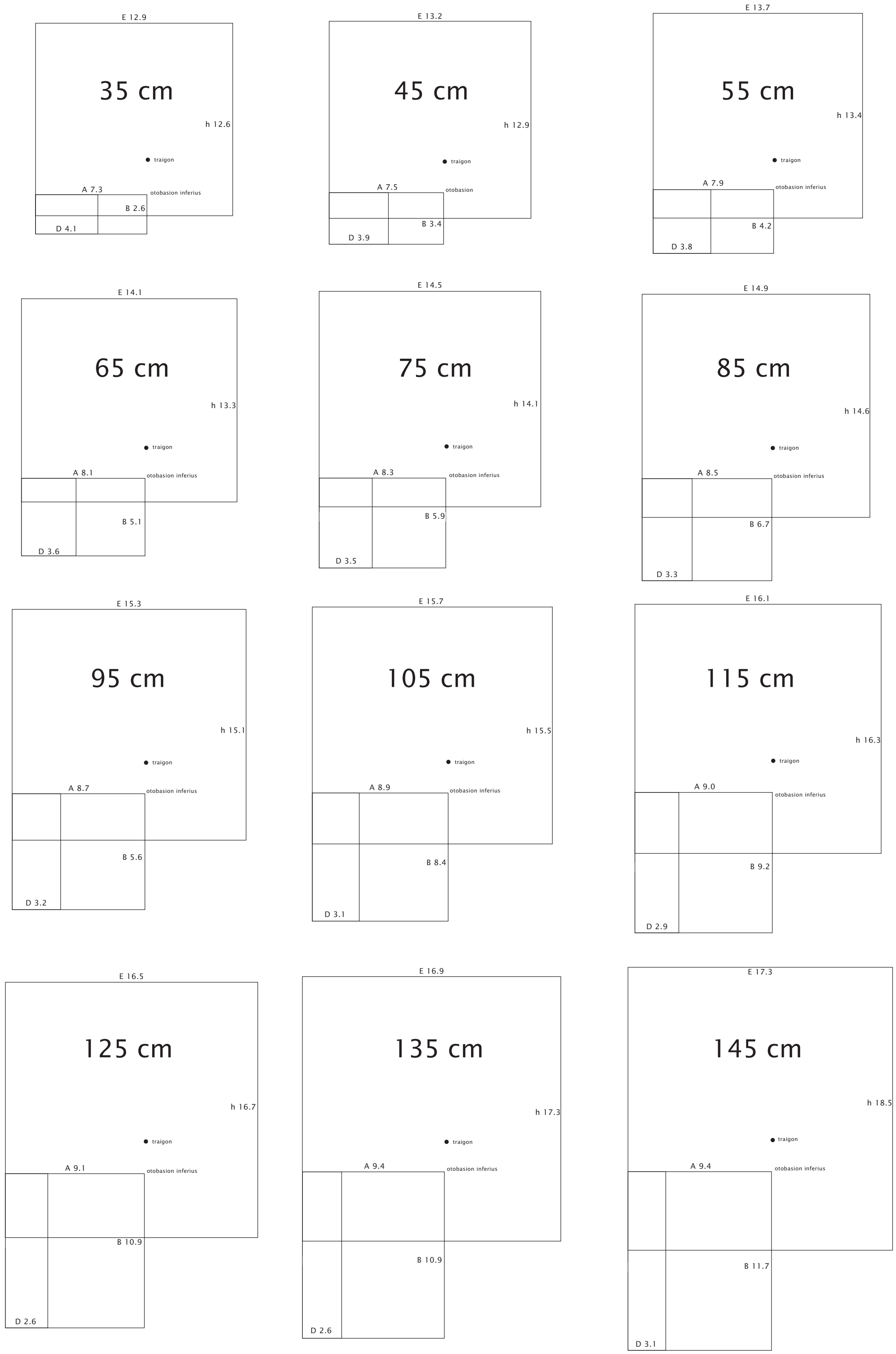


Figure 28c. Non- superimposed HNSC box diagrams of the predicted averages based on height arranged in ascending height order and aligned by traigon. All reduced by same factor to scale.

Discussion and Assumptions

Study Design

This study shows that simple measurements taken with simple equipment can provide a reliable dataset of clinical value and can be correlated with other datasets for validity. More technologically sophisticated modalities can be utilized to collect measurements on children such as radiography and infrared scanning devices. These techniques may be less than ideal for a number of reasons: 1) x-rays can be harmful for healthy children 2) infrared scanning requires cooperation from the child to stay perfectly still 3) the scanning beam may be potentially dangerous 4) radiographs and infrared scans are costly. Datasets such as those collected from Snyder and Schneider used sophisticated measurement equipment to give precision measurements, however, the variability of head and body positioning, the tendency for children to move and their limited ability to cooperate may make the use of these precision instruments less than reliable.

There were a number of assumptions made in the process of study design. The reality of measuring children plays a large part in both the design of the study and quality of the results. The behavioral and developmental aspects of children result in them being mobile and often minimally cooperative. While it may be argued that a tape measure is not a precision instrument, the use of a simple, non-threatening measuring device may enhance the ease and quality of the measurements taken in the pediatric environment. As other related studies have shown landmarks are fuzzy, and thus precision instruments may or may not improve, in net effect, the accuracy of the true measurement. Given the sample size and practical considerations of this study, measurements in half- centimeters provide sufficient detail. Also, the consistency of having a single data collector likely lowered interrater error.

The differences in design of this study limited the degree to which others data could be utilized for supplementation and comparison. For example, Snyder uses the traigon as the ear landmark while this study uses the otobasion inferius. To correct for this discrepancy, an estimation of two centimeters was made for traigon to otobasion inferius distance. Although using the traigon as an anthropometric landmark in this study, would have resulted in a more precise measurement, the estimated distance error is negligible.

The average size and shape of a population of people in similar age groups may change over time. The time passage between the data collection in from Snyder, Schneider and this study could be a source of error when comparing data.

This study population may not be representative of the current US population. This study measured a small population in East Baltimore; an economically depressed city area with high rates of low birth weight, poverty, low health status and chronic disease. The population sample was ninety five percent African American. These patients were present in an emergency department and outpatient clinic and not necessarily representative of the healthy urban community. The multiple socioeconomic issues, nutritional status, health status and ethnicity may not be typical of the broader spectrum of the United States society.

Snyder and Schneider measured healthy children, attending schools and daycare centers. Their populations are more representative of the United States population. The low birth weight of our population sample most likely contributes to the generally smaller heads in this study when compared to those of Snyder and Schneider.

The Visual Representations

"Every part of the whole must be in proportion to the whole" (daVinci). Thus daVinci recognized that there is an apparent relationship between human anthropometric measurements. The HNSC boxes allowed us to make visual comparisons in size and shapes of the measurements of the HNSC based on an individual observation, an average, or a predicted average. By placing a number of the scaled HNSC box diagrams onto a single plate based on a specific form of grouping, they could be compared more easily and trends could be observed (Figure and 21b, and 29). It is

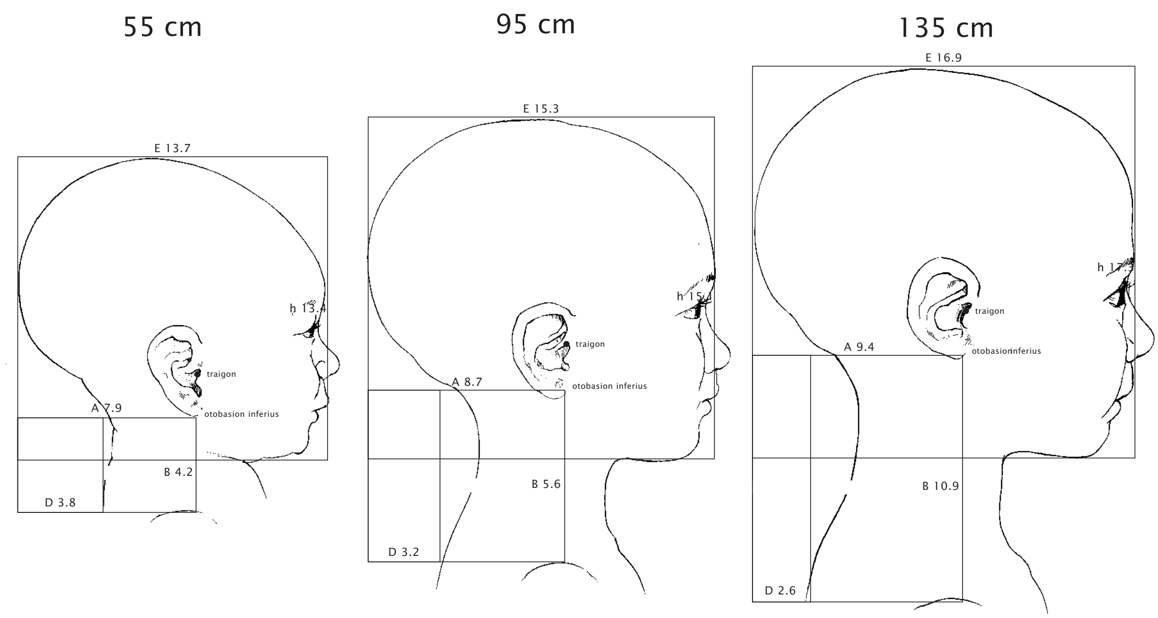


Figure 29. Predicted HNSC diagrams for 35cm, 95 and 135 cm.

much easier to compare the HNSC box diagrams to one another when they are on the same page (Figure 29) rather than separate pages (Figures 25, 26, and 27). Given the symmetry of the head, the boxes provide a frame in which a lateral silhouette of a head can be drawn. The silhouette is an estimation only. The actual data lies with in the boxes. A graphic does not distort if the visual representation of the data is consistent with numerical representation (Tufte, 1983). The representation of numbers, as physically measured on the surface of the graphic itself, should be directly proportional to the numerical quantities represented (Tufte, 1983). Because the HNSC box diagrams such as seen in Figure 29, are consistent with the numerical quantities, they do not distort the data.

Much of the literature and collar manufacturer recommendations suggest using the patients age as the standard for determining proper immobilization device size. In this study, age was challenged as the standard in sizing for immobilization devices. Age may not be the most indicative predictor of neck size and therefore collar size. In order to determine which variable (age, height of weight) may be the best predictor of neck size, for this study, neck height (line B) was chosen as an important measurement. Neck height appears to be a critical measurement for collar size and it appears to change minimally regardless of neck position. Also, neck height is a dimension in which there is variability among currently available collars for different age groups.

Compared with age and weight and height, height proved to be the best predictor of neck height. For this reason, the predicted HNSC box diagrams, used to visualize trends in the HNSC, were sorted based on height instead of weight of age. Another worthwhile exercise would be to create predicted HNSC box diagrams, like those created for height, only based on certain age groups.

The difference in age groupings (Figure 19) between different datasets limited the degree to which overlapping of the data was possible. Because this study sample size was considerably smaller and the age stratifications were different than those of Schneider and Snyder, the same age groupings could not be applied. When creating a HNSC based on an individual or an average, the proportion calculation was used to keep the HNSC box diagram proportions in accordance with Snyder or Schneider's head proportions, even if the general head size of an individual observation in this study was much larger or smaller than the average size of a given Schneider or Snyder age group.

When using Snyder and Schneider's data to provide additional measurements (head height, traigon to vertex, vertex to shoulder) as seen in Table 3, it would have been more accurate to have used untabulated data from their original observations. The untabulated data could have been grouped by whichever way it would have been best to group this study data. Each variable group average (A-E and HC) could have been determined from averaging a group of Sch/Sny observations with exact heights instead of using Sch/Sny average height values based on pre-grouped ages. For example, suppose you wanted to determine the additional measurements for a 48 cm child. Since Schneider and Snyder report their results in groups based on age, first it must be determined which Schneider and Snyder age grouping a 48 cm child would fit into (which happens to be the 0-3 month group with an average height of 55 cm). All of these additional measurements being created for the 48 cm child are then based on a child with an average height of 55 cm. For determining the additional measurements, it would be more accurate to use the means all the desired variables (head length, head height, traigon to vertex, vertex to shoulder) from Schneider's observations that measured 48 cm, instead of using the variables based on a 0-3 month old that averages 55 cm.

When creating the predicted average HNSC box diagrams for this study by averaging subgroups together, sample size within each subgroup impacted on the number of possible subgroups. If more narrow strata (5 cm instead to 20 cm groupings) would have been used to determine the averages based on height, it may have given different, perhaps more detailed results. However, dividing this study's data into more narrow strata would have resulted in subgroups with a very small sample size. The average of three individual's measurements was not considered adequate to represent an entire age or height group.

When averages of the 20 cm strata were plotted, any variable (values of A-E or HC) could be determined at a given height if that height was entered into the equation of the line of best fit (Figure 23). Each variable value was determined at twelve, 10 cm height increments to give an indication of the growth trends of the HNSC. Also, a sufficiently smooth animation could be created by stringing these close intervals together. For the visualizations of the predicted averages HNSC box diagrams as seen in Figure 28, the starting height of 35 cm was chosen because it was the approximate height of the smallest child measured in this study. Since most children younger than 10 years were under 145 cm, this height was chosen the be the greatest.

When comparing the predicted average small, medium and large HNSC box diagrams (Figures 25, 26, 27 and 29) from the twelve that were created, the 55 cm HNSC box diagram was chosen as the best representative of the smallest HNSC because this is approximately the average height of Schneider's first age group (0-3months). The 135 cm HNSC box diagram was used for the largest representative because in this study, most children, eight years of age, fell under this height.

It was expected that line D (the distance between the back of the shoulder at the level of the shoulder crest to the occipital point) would decrease with increasing age and height. And in fact, this study shows that the magnitude to which line D changes is greater than estimated in published studies which are not based on population based data (Nypaver).

In the process of research for this study, the drawings by daVinci and Dürer were come upon by the author after the HNSC box diagrams had been developed. It was surprising to discover that daVinci and Dürer had also used box-type diagrams to describe the measurements of the head and body. The child vs. adult line D comparison can even be found in Dürer's work, when a child head and adult head are placed together as seen in figure 30. daVinci, can be referenced not only for the content of his research but also for his highly communicative design style with integration of text, and figure (Tufte, 1983). These old master drawings exemplify past efforts to describe head and body proportions visually and provide a comparison for the visualizations created in this study.

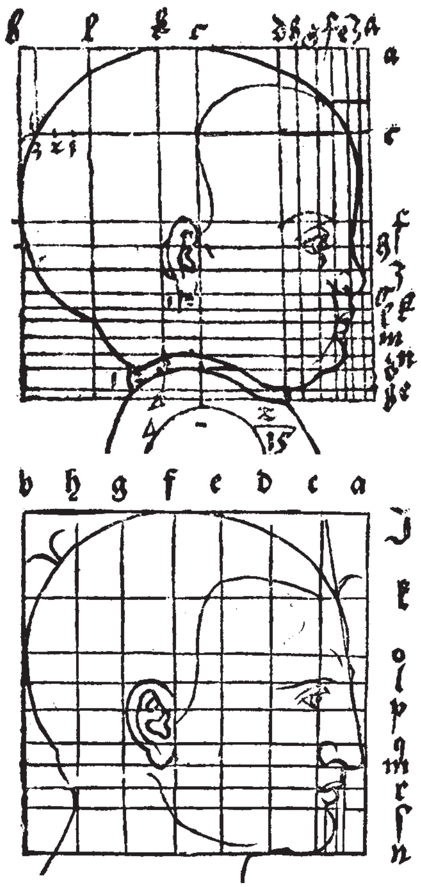


Figure 30. Adapted from figures by Albrecht Dürer showing the head proportions of a child on the top and adult on the bottom from *Les qvatre livres d'Albert Dürer…De la proportion des parties & pourtraicts des corps humain*.

Given how these data represented the shape and size of the HNSC especially for the younger patient, it appears highly unlikely that a "Baby No-Neck" collar would, in any practical way, fit a baby. As shown in Figure 24, children aged 6 weeks, 2 years, 4 years and 6 years are all wearing the same "baby no-neck" collar. The collar appears to best fit the 4 and 6 year old. Their chins rest on the chin piece although their heads may be in slight flexion and their necks in slight extension. The 2 year old, while her chin is also rests in the chin piece, appears to have her head in flexion and neck extended. The 6 week old cannot even rest his chin on the chin piece. The lateral height collar measurement is about 12 cm (not including the foam padding) at the point of the sizing post. According to this study's data, the average line B measurement for a 55 cm baby is 4.2 cm. Positioning a baby in such a device would likely place the neck into flexion and minimally achieve immobilization.

Further Studies

Neutral position was estimated because there is no scientifically accepted definition radiologically or clinically. An accepted definition of neutral position should continue to be sought out.

The lack of clear parameters for how a cervical spine collar should fit children and adults hindered the determination of the most critical measurements for collar size.

Head height measurements from this study original observations would have been helpful for the ease of reconstruction the HNSC proportions, but had little bearing on determining the relative HNSC measurements of interest in this study. This measurement, as well as others, would have eliminated the need for mapping from Snyder and Schneider and thus calculating the ratio of proportions to estimate head height or other measurements. It would have been efficient to use the traigon as an anthropometric point in line B instead of the otobasion inferius. Including line F from the start of measurement collection would have allowed its use in creating the predicted average HNSC based on height. Also, line F (gonion point to shoulder crest), is the dimension which Laerdal Inc. recommends measuring for proper collar sizing, instead of the otobasion to shoulder crest dimension, as this study measures for neck length. This study could be refined with a larger and broader sample size and additional measurements taken.

To our knowledge, there is no recorded or published data of these measurements of the HNSC in consideration of neutral position or for the purpose of collar design. Snyder describes numerous other anthropometric studies of children. These lack the many specific measurements needed for a detailed study of the head neck and shoulder complex in consideration that it is a dynamic structure.

Conclusion

This study provides a way at looking at a large numerical datasets visually and statistically. HNSC box diagrams were useful for visualization of an individual head as well as trends in the size and shape of the HNSC. Given that trends are indicating increased incidence of cervical spine injury (Luchter), these issues of immobilization appear to be increasing in importance and thus reinforce the need and value of interdisciplinary studies such as this. In addition, measurements compiled in this study may serve as pilot data that guide interdisciplinary development of new perspectives on data collection in this area. The issues addressed in this study extend beyond improving collar design to encompass the improvement of all emergency medical service equipment where design should be dependent on accurate communication of anthropometric descriptions. The application of accurate visual descriptions of this anthropometry can have far-reaching theoretical and clinical value in the care of the critically injured child.

Table 4. Anthropometric Data Collected

study#	age years	height cm	weight kg	headCirc.	ineA cm	ineB cm	ineC cm	ineD cm	ineE cm
1	0.0	50.5	3.2	34.5	9.0	2.5	2.5	7.5	13.5
2	5.7	112.0	18.0	50.5	12.0	9.0	10.0	6.5	18.0
3	5.3	114.0	20.8	55.0	11.0	9.0	6.0	3.5	19.0
4	2.5	81.3	12.2	50.5	10.5	4.5	3.5	4.5	17.5
5	1.3	31.5	9.1	46.0	8.5	5.0	4.5	5.5	14.5
6	6.0	119.0	19.8	52.0	11.0	9.0	7.0	4.5	19.5
7	8.7	129.0	25.0	54.0	11.5	12.0	7.0	4.0	19.5
8	3.2	93.0	12.8	51.0	8.0	8.0	6.0	4.5	15.0
9	9.0	130.5	28.0	51.5	8.5	11.0	7.0	5.0	16.5
10	8.8	128.5	33.1	51.5	8.5	10.0	7.5	2.5	18.0
11	11.2	132.5	41.4	54.5	9.5	11.5	8.0	2.0	17.0
12	9.1	130.0	26.2	53.0	7.5	10.5	8.0	1.5	16.0
13	5.7	106.5	14.9	47.5	10.0	7.5	7.0	2.5	17.0
14	0.5	73.7	10.3	47.0	8.5	4.0	3.5	3.5	13.5
15	3.8	111.0	17.4	50.0	9.5	9.5	6.0	2.5	17.5
16	5.1	103.0	15.3	50.0	10.0	7.0	4.0	3.0	17.5
17	0.5	41.9	6.9	41.0	7.5	5.0	4.0	3.0	14.0
18	11.6	148.0	35.4	53.0	8.0	13.0	8.0	2.0	17.0
19	0.6	65.0	8.0	43.5	6.5	5.0	4.5	2.5	13.5
20	12.2	155.5	55.0	58.0	12.0	12.0	12.0	4.0	21.0
21	14.8	166.0	108.6	64.0	12.0	10.0	10.0	3.0	18.0
22	1.0		8.2	46.0	7.0	4.0	4.0	3.0	17.0
23	7.6	134.5	29.7	54.0	9.5	9.5	9.0	4.5	17.5
24	9.8	140.5	33.7	56.0	11.0	11.5	9.5	2.5	19.0
25	1.2	75.0	12.4	49.0	8.0	4.0	3.5	2.5	17.0
26	8.9	146.0	42.5	52.5	9.0	13.0	10.0	3.5	17.0
27	0.3	55.0	5.9	42.0	7.0	3.5	3.5	1.5	14.0
28	9.1	132.0	35.7	52.5	9.0	10.0	8.0	2.0	16.0
29	5.8	118.0	22.4	55.0	10.0	8.0	10.0	3.0	19.0
30	5.5	113.0	20.3	52.5	8.5	8.5	7.0	3.5	18.0
31	6.5	132.0	31.9	53.0	8.0	9.5	7.5	2.5	15.0
32	3.0	113.5	25.8	53.0	10.0	10.0	7.0	2.0	19.0
33	5.3	114.0	21.1	52.0	10.0	9.0	6.0	4.0	17.0
34	2.3	92.5	11.7	49.5	10.5	8.5	7.0	4.0	14.5
35	7.2	127.0	49.6	51.8	8.0	8.5	6.0	3.5	15.5
36	7.2	114.5	47.5	53.0	8.5	9.0	5.0	5.5	16.0
37	8.0	125.0	53.5	50.5	10.0	11.0	8.0	4.5	15.0
38	4.8	114.0	17.3	54.0	9.0	10.0	6.0	3.5	17.0
39	0.1	55.9	4.1	40.0	10.0	5.0	4.0	6.0	14.0
40	9.0	141.5	54.4	59.5	11.0	11.0	8.5	2.0	17.5
41	12.6	151.0	40.7	56.0	9.0	12.0	6.5	3.0	16.0
42	0.7	71.1	8.5	44.0	6.0	5.0	3.0	3.0	12.0
43	3.9	108.0	15.4	49.5	10.0	7.5	6.0	4.5	16.0
44	2.0	78.0	13.2	48.0	9.0	8.5	4.5	3.5	15.0
45	8.7	135.5	34.0	56.5	9.0	11.0	6.5	2.5	16.0
46	11.8	141.0	47.2	56.0	10.5	12.0	5.0	1.0	17.0
47	4.3	109.5	20.8	56.0	11.0	9.5	6.5	4.0	17.0
48	3.9	100.0	16.1	53.5	10.0	9.0	5.5	5.0	16.0
49	7.9	138.5	33.1	55.0	9.5	11.5	8.0	4.5	18.0
50	8.2	138.5	49.3	55.0	10.0	9.5	6.5	3.5	17.0
51	2.9	99.0	16.6	51.0	8.5	8.0	5.5	3.5	16.0
52	9.7	135.0	38.7	55.5	9.0	11.0	7.0	3.5	18.5
53	13.6	142.5	38.0	54.0	8.0	12.5	9.0	3.0	17.0
54	6.2	129.0	28.7	54.0	6.0	11.5	6.0	1.0	16.0
55	9.1	145.5	52.9	56.0	9.0	13.0	9.0	2.0	17.0
56	7.2	121.0	47.3	52.5	8.0	11.0	7.0	2.5	15.5
57	1.1	68.0	19.3	46.0	9.0	7.0	2.5	3.5	13.0
58	8.1	134.0	24.5	52.5	8.0	10.0	5.0	2.5	16.0
59	4.9	115.5	18.3	50.5	8.0	8.5	5.5	3.0	14.0
60	1.2		8.6	45.5	8.0	7.0	6.0	3.5	14.0
61	4.0			53.5	10.0	7.5	5.0	3.0	16.0
62	0.0	38.1	2.3	33.0	7.0	2.0	4.5	4.5	11.0
63	2.8	91.0	14.0	48.0	9.0	8.0	5.0	3.0	15.0
64	0.1			37.5	9.0	4.5	3.0	4.5	13.0

Table 4 continued. Anthropometric Data Collected

study#	age years	height cm	weight kg	headCirc.	ineA cm	ineB cm	ineC cm	ineD cm	ineE cm
65	4.2	112.5	22.2	52.5	9.0	9.0	7.0	2.0	17.5
66	0.2	51.0	5.2	41.5	9.0	4.0	3.0	4.0	16.0
68	5.3	119.5	20.5	51.5	10.0	10.5	6.0	3.5	16.0
69	10.8	156.0	67.2	55.5	10.5	12.0	7.0	1.0	16.0
70	0.7	66.0	10.4	46.0	9.0	5.0	2.0	3.5	13.0
71	3.7	102.0	14.1	48.5	8.5	9.5	4.0	3.5	14.0
72	0.7	64.0	8.5	44.5	7.5	5.0	2.0	3.0	15.0
73	0.4	50.0	5.4	41.0	7.5	3.0	1.5	3.0	14.0
74	5.6	111.0	18.5	52.0	8.5	8.5	5.5	2.5	15.0
75	3.8	105.0	16.4	53.5	10.0	9.0	4.5	3.0	17.0
76	9.5	127.0	27.5	56.5	8.0	10.0	6.0	3.0	17.0
77	3.1	102.0	16.9	52.0	8.5	9.0	4.5	3.0	15.0
78	2.7	90.0	11.1	45.5	7.5	8.0	6.5	3.0	12.5
79	1.0	74.5	9.0	48.5	8.0	5.5	4.0	3.0	15.0
80	0.0	47.0	3.4	35.0	5.5	2.5	2.5	4.5	11.0
81	6.8	126.0	16.1	51.5	7.0	11.0	6.0	3.0	13.5
82	9.2	140.0	35.6	53.0	7.5	13.0	8.5	2.5	14.0
83	9.8			54.0	7.0	10.0	7.0	4.0	16.0
84	0.1	55.0	4.9	39.5	8.0	3.0	2.0	4.0	12.0
85	9.0	133.0	28.7	52.5	9.0	12.0	6.5	2.5	15.0
86	7.8	133.0	30.6	54.0	7.5	10.5	6.0	4.0	16.0
87	1.0			47.0	9.0	7.0	4.0	5.0	13.0
88	1.1	74.9	9.4	45.0	8.0	7.0	4.0	2.0	16.0
89	0.2	53.0	4.5	40.0	7.0	3.0	2.5	3.5	13.0
90	7.1	125.0	27.7	54.0	6.5	9.0	4.5	1.5	15.0
91	0.4			42.0	7.0	4.0	3.0	3.0	15.0
92	6.4	121.0	21.3	54.0	8.5	10.5	5.5	3.0	16.0
93	3.4	103.0	16.1	53.0	8.0	8.5	4.5	4.0	16.0
94	10.4	136.5	29.2	61.5	9.0	10.5	4.5	2.5	18.0
95	5.1	113.0	18.5	53.0	8.5	9.5	5.0	3.0	17.0
96	1.2			52.5	8.0	5.5	3.5	4.0	13.5
97	2.9	97.0	15.1	53.0	7.0	7.0	6.5	4.0	15.0
98	6.9	130.0	33.6	54.0	9.0	11.0	6.0	1.5	16.0
99	8.3	143.0	34.3	54.0	9.0	13.0	6.0	2.0	16.0
100	7.8	129.0	24.1	53.5	9.0	11.0	6.0	3.0	15.5
101	5.3	111.5	17.3	51.0	9.0	9.5	6.0	1.5	13.0
102	0.0	55.9	3.6	35.0	6.5	2.5	2.0	3.0	12.0
103	5.5	115.0	23.4	52.0	9.5	9.0	6.0	3.0	15.5
104	0.6	58.4	7.3	45.0	8.0	6.0	2.0	3.0	13.0
105	6.6	122.0	20.0	52.0	8.0	9.0	5.5	2.0	14.0
118	6.9	128.0	26.1	54.0	10.0	12.5	8.5	2.0	14.5
119	0.8		9.1	47.0			4.5		
120	8.0	128.0	24.8	51.0	8.5	8.0	4.0	2.0	15.5
121	1.6	87.0	12.2	48.0	9.0	6.0	5.0	2.0	14.0
122	1.9			47.5	7.5	4.0	5.0	1.0	14.5
123	6.8	122.0	21.4	52.5	7.0	10.0	6.0	2.5	16.0
124	3.5	98.0	13.2	49.5	8.0	8.0	5.5	1.5	13.0
125	0.6	68.6	8.2	45.0	7.0	4.5	3.0	2.5	14.0
126	1.3	70.0	10.9	48.5	8.0	6.0	4.5	3.0	15.0
127	9.6	149.5	38.5	54.0	7.5	12.0	6.5	1.5	17.5
128	0.8		7.7	46.5	9.0	5.0	3.5	3.5	14.0
129	4.0	101.0	16.0	49.0	8.5	8.5	4.5	1.5	14.0
106	1.0	73.0	8.4	45.0	8.0	6.0	3.0	2.0	15.0
107	7.8	133.0	64.0	54.5	10.0	9.0	9.5	2.0	19.0
108	5.4	122.0	22.0	55.0	8.0	9.0	6.0	2.0	17.5
109	2.7	97.5	13.8	52.5	8.5	7.0	5.0	3.5	17.0
110	1.1	77.0	10.9	51.0	8.5	7.0	4.0	2.5	16.0
111	0.9		9.2	48.0	8.0	6.0	4.5	3.5	15.0
112	2.9	98.0	15.0	51.0	10.0	8.0	4.5	2.0	15.5
113	3.2	105.0	17.3	51.0	9.5	9.5	5.5	2.5	15.5
114	4.9	112.0	18.9	55.0	10.0	8.0	6.5	2.5	17.0
115	4.4	114.0	16.4	49.0	8.0	10.0	5.5	2.0	15.0
116	8.7	103.0	15.9	51.5	10.0	7.0	3.5	2.0	15.0
117	3.2	124.0	21.7	53.0	9.0	9.5	7.0	2.5	16.0

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Vita

The author was born in Westlake Village, California on September 29, 1974, where she lived for the majority of seventeen years. She graduated from Westlake High School in the spring of 1992 and with her family, moved to High Point, North Carolina. From the autumn of 1992 until the spring of 1993 she attended the School of Fine Art at Carnegie Mellon University in Pittsburgh, Pennsylvania. In the autumn of 1993 she transferred to Wake Forest University in Winston-Salem, North Carolina. She accomplished a major in fine art, a minor in biology and a concentration in pre-medicine. In 1996, she exhibited fifteen paintings at in a one-woman show and attained Honors in Art at Wake Forest University. In 1997, she studied fresco painting and restoration, drawing and Italian language at Scuola Lorenzo dé Medici in Florence, Italy. She graduated with honors from Wake Forest University in the spring of 1997 with a Bachelor of Arts.

In the autumn of 1997, the author entered into the graduate program in Art as Applied to Medicine at the Johns Hopkins University School of Medicine in Baltimore, Maryland. During the summer of 1998, she worked as a visual information specialist for the National Library of Medicine at the National Institutes of Health in Bethesda, Maryland. There, she created an animation describing the immune response in asthma for the exhibit "Asthma, the Breath of Life". The author is currently completing requirements for the degree of Master of Arts, which is to be awarded in May of 1999.