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Relative Velocity of Accretion of Weight and Height Using the Benn Index in the First Nine Years of Life

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Summary

Using the power ponderosity index of Benn, weight (W)/height (H)^p, (W/H^p) where the value of p is determined so that the correlation of height and W/H^p is zero, a set of p values was obtained from longitudinal data of 630 healthy, white, middle class children ranging in ages from birth to 9 years. Our data revealed two turning points in the relative velocity of change of height and weight not previously recognized by separate studies of velocity changes in weight and height related to chronological age. The value of p increased from birth (1.72) until about 1 month (2.39) for girls, and 5 months for boys (2.30), the first turning point, and then fell to a nadir at age 18–21 months for girls (1.75) and 21–24 months for boys (1.73), the second turning point. This fall to the nadir represents the greater influence of velocity change in height over weight. From then to age 9 years, there was a gradual and steady increase in p, greater for girls than for boys, representing the greater influence of velocity change in weight over height. The values of p have now been estimated for white, middle class children over the ages of birth to 9 years and may have utility in studies which compare obesity indicators.

Abbreviations

W, weight
H, height
W/H^p, Benn's power index

The two most easily measured and relatively accurate clinical indices of growth, W, and H are only indirect measurements of relative fatness (6, 9, 13). The direct methods of determining relative fatness include somatotyping, skinfold measurements, hydrostatic determinations of density, and chemical isotope dilution. All have limitations or cannot be done in clinical practice (4, 9, 13). The indirect methods designed to quantitate relative ponderosity include calculating relative weight for height, or some power function of height, (W/H, W/H^2, $W/H^{1/3}$) (4, 9). The calculations of W/H, W/H^2, $W/H^{1/3}$ (4, 9) are performed in an attempt to limit the correlation of weight to height (1, 4), but they fail to do so (4, 8). The best indirect index would be one that has no correlation to height (1, 5, 9, 10). The use of a power index to determine relative fatness of children is further complicated by the progressive and expected changes in height from infancy to the end of adolescence.

To overcome these limitations, Benn (1) has proposed the use of a power index, W/H^p, where the exponent p, not limited to whole numbers, is that power of H, which enables the correlation between the ratio W/H^p and the height to be zero. In the equation of Benn, $b = p\ \bar{w}/\bar{h}$; $\bar{w}$ and $\bar{h}$ are the average height and weight for the age groups being considered, and b is the slope of Benn's arithmetic regression model, *i.e.*, dW/dH. This can be rewritten as $(dW/dt)/(dH/dt)$, the relative velocity of height and weight.

Thus, examination of Benn's Figures 1 and 2 (1) which plot the slope of b (or p) against weight and height demonstrates that as the value of the slope increases, the relative importance of weight gain becomes greater. Conversely, as the value of the slope decreases, the relative importance of height gain becomes greater. Thus, in growing children, changes in p or b represent changes in relative velocity of height and weight change.

We have longitudinally followed and reported upon a relatively homogeneous population of 630 children from birth to 9 years of age who are white, middle class, suburban, and have received both nutritional supervision and measurements by the same pediatrician (3). The absence of malnutrition, child neglect and/or abuse, and the stable longitudinal follow-up of this cohort allowed evaluation of relative velocity of accretion of weight and height, with limited confounders, in healthy children. We do not know, however, how well our estimates of p and b can be generalized to biracial and/or low socioeconomic status groups of children. The purpose of our current report on this cohort, using paired height and weight data, is to calculate the changes in the value of p and b over the first 9 years of life, to better assess the relative velocity of height and weight change.

MATERIALS AND METHODS

The 630 children for study were selected from a middle class private practice (3); the data were obtained with informed consent. The methods of selection, the means of measurement, the transcription on the computer tape, and the methods of statistical analysis have previously been described (3). The set of children was selected for the study using the following criteria. 1) They had been seen for routine child health care from birth, in a single suburban pediatric practice. 2) They weighed more than 5½ lb at birth. 3) They had no chronic or congenital illness that would affect normal gain in height and weight. 4) They were white children in the middle to upper-middle social class. 5) They were in the current files of the practice in September 1975. Infants were measured for both height and weight on an office platform scale graduated in pounds and inches. Infants were totally undressed, including diaper, for each weight measurement. Weight was measured to the quarter ounce. Length was noted to the nearest quarter inch using horizontal bars for both head and feet.

By age 2, the children were studied standing on a scale that measured both height and weight. Older children wore only underpants when weighed. Since all of the children had height and weight measurements done in a consistent manner by a single pediatrician in a stable practice setting (3), interobserver variance in measurement error should be at a minimum, allowing more stable estimates of p and b.

The exponent p of the formula of Benn (1), W/H^p, was determined for selected ages, so that the correlation of height and W/H^p was zero. This was done for each of 21 ages ranging from birth to 108+ months of age (Figs. 1 and 2) (Table 1), separately for boys and girls. Birth measurements included birth to 15 days of life; age 1 month (15–45 days); age 2 months (45–75 days), etc., up to and including age 5 months. From 6 months on, the segment method was used, as described previously (3).

In addition to p, the slope b was also calculated at each age using the formula described by Benn (1), $b = p\,\bar{w}/\bar{h}$, where $\bar{w}$, $\bar{h}$ are the average height and weight for the age groups being considered (Fig. 3, Table 1).

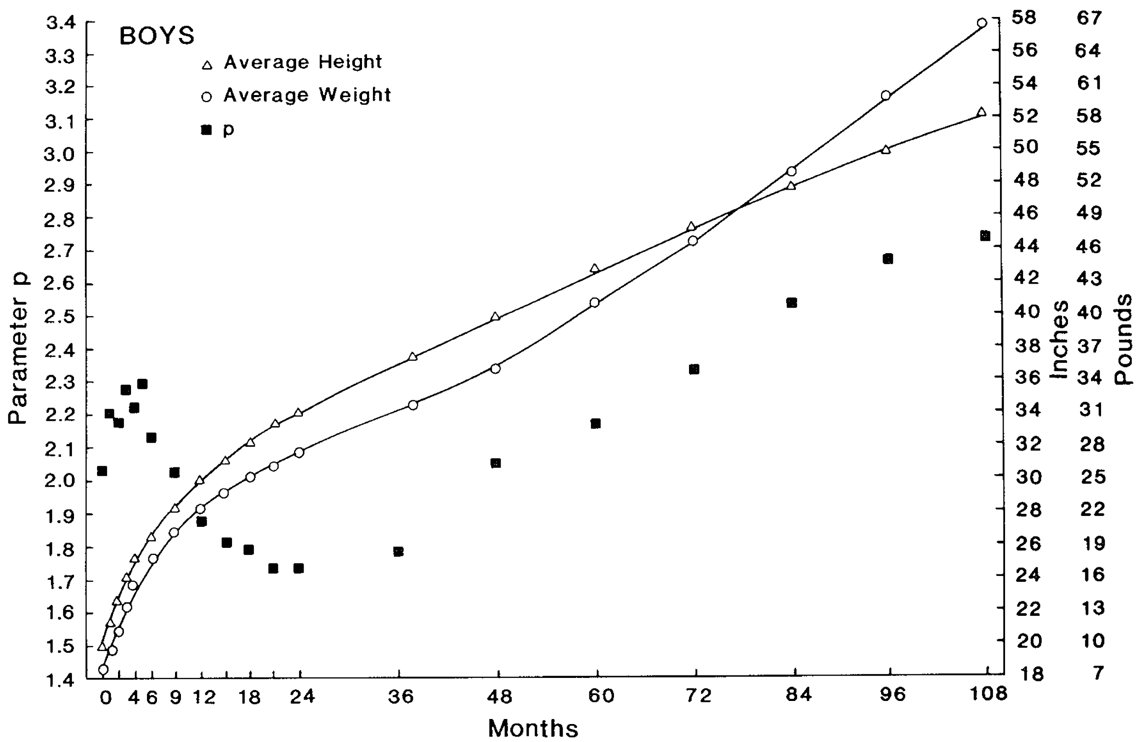

Fig. 1. Values of parameter p of Benn's index (W/H^p) from birth to 9 years for white healthy boys, where p is the slope of the logarithmic regression model of Benn (1). Average height and weight changes are also displayed.

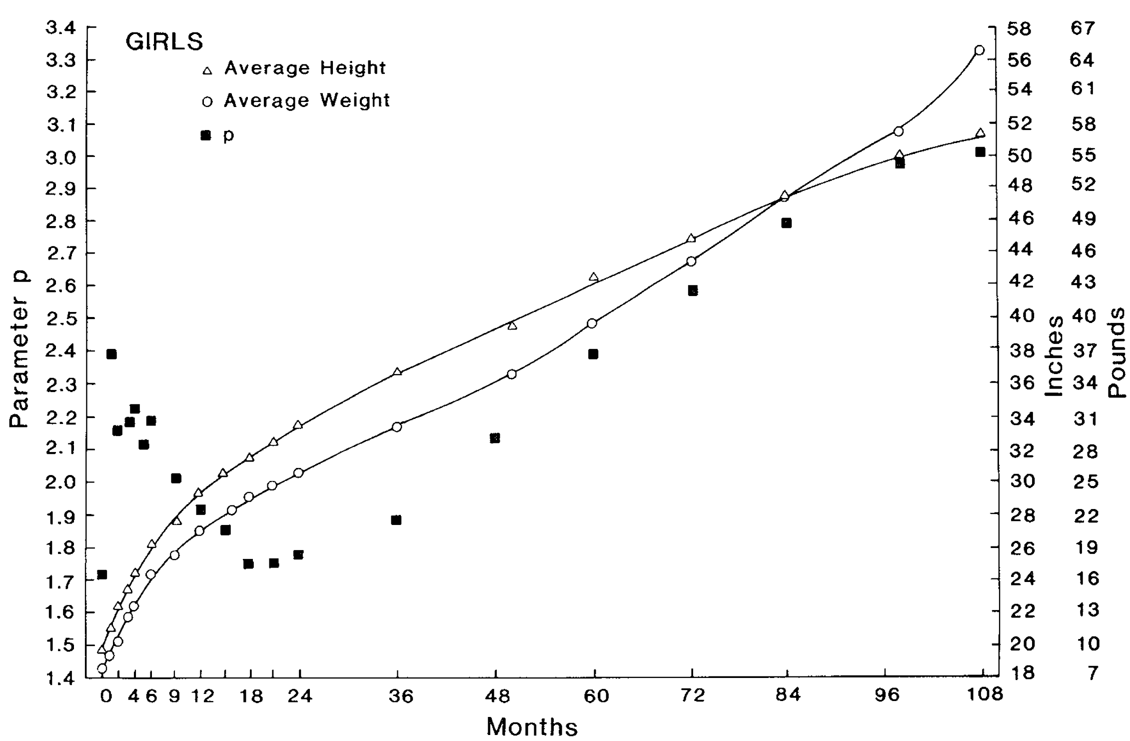

Fig. 2. Values of parameter p of Benn's Index (W/H^p) from birth to 9 years for white healthy girls, where p is the slope of the logarithmic regression model of Benn (1). Average height and weight changes are displayed.

Thus, substituting in the equation $b = p \times \bar{w}/\bar{h}$ using the data on 3-month-old boys from Tables 1 and 2 as an example yields the identity $1.29 = 2.27 \times 13.7/24.09$. According to the two models given in Benn (1) which relate to height and weight, p represents the slope of the logarithmic regression model, and b is the slope of the arithmetic regression model.

RESULTS

The data represent 9,448 paired height and weight measurements of 630 white, middle class children from a single surburban pediatric practice. Six hundred one children were followed for 5 years, and 279 were followed for at least 9 years.

The values of p and b are displayed in Figures 1–3 and Table 1. The values of p change constantly throughout the 9 years of study. At birth, boys and girls have widely differing values of p, 2.04 and 1.72, respectively. At 1 month values have risen to 2.21 and 2.39, an 8.3% increase for boys (Fig. 1) and a 39% increase for girls (Fig. 2). Values for girls decline from this point but those for boys increase to 2.30 at age 5 months (a maximum 12.7% rise) before declining. The nadir for boys is reached at 21–24

Table 1. *Values of the parameters* p, *and* b *by age and sex of Benn's index (1)* $\overline{W}/\overline{H}^p$ *and* $p = b\,(\overline{H}/\overline{W})$

Age (months)	*p*		*b*		*n*	
	Males	Females	Males	Females	Males	Females
Birth	2.04	1.72	0.77	0.64	261	271
1	2.21	2.39	0.97	1.01	270	278
2	2.18	2.15	1.12	1.04	303	320
3	2.27	2.17	1.29	1.16	309	321
4	2.23	2.23	1.35	1.27	309	321
5	2.30	2.12	1.46	1.27	309	321
6	2.13	2.19	1.41	1.36	309	321
9	2.03	2.02	1.45	1.36	309	321
12	1.88	1.93	1.40	1.36	308	321
15	1.81	1.85	1.37	1.34	307	319
18	1.78	1.75	1.38	1.29	307	319
21	1.73	1.75	1.37	1.32	306	319
24	1.73	1.77	1.39	1.37	306	319
36	1.79	1.88	1.54	1.56	306	315
48	2.05	2.14	1.87	1.89	303	313
60	2.16	2.38	2.09	2.23	286	296
72	2.33	2.57	2.40	2.56	241	242
84	2.53	2.79	2.81	2.99	202	204
96	2.66	2.97	3.18	3.42	168	173
108	2.73	3.04	3.50	3.80	140	138

Table 2. *Mean values of height (inches) and weight (pounds) by age and sex*

Age (months)	Males			Females		
	$\bar{H}$	$\bar{W}$	*n*	$\bar{H}$	$\bar{W}$	*n*
Birth	19.99	7.52	261	19.65	7.26	271
1	21.48	9.40	270	21.12	8.91	278
2	22.86	11.73	303	22.41	10.83	320
3	24.09	13.70	309	23.53	12.53	321
4	25.16	15.28	309	24.55	13.98	321
5	26.06	16.60	309	25.40	15.19	321
6	26.83	17.77	309	26.12	16.23	321
9	28.57	20.44	309	27.86	18.71	321
12	30.01	22.28	308	29.31	20.59	321
15	31.21	23.68	307	30.51	22.05	319
18	32.27	25.02	307	31.63	23.53	319
21	33.22	26.25	306	32.61	24.65	319
24	34.06	27.45	306	33.49	25.85	319
36	37.05	31.88	306	36.62	30.36	315
48	39.89	36.34	303	39.52	34.92	313
60	42.70	41.26	286	42.24	39.50	296
72	45.32	46.73	241	44.86	44.73	242
84	47.72	53.06	202	47.31	50.68	204
96	49.98	59.70	168	49.55	57.08	173
108	52.16	66.97	140	51.75	64.69	138

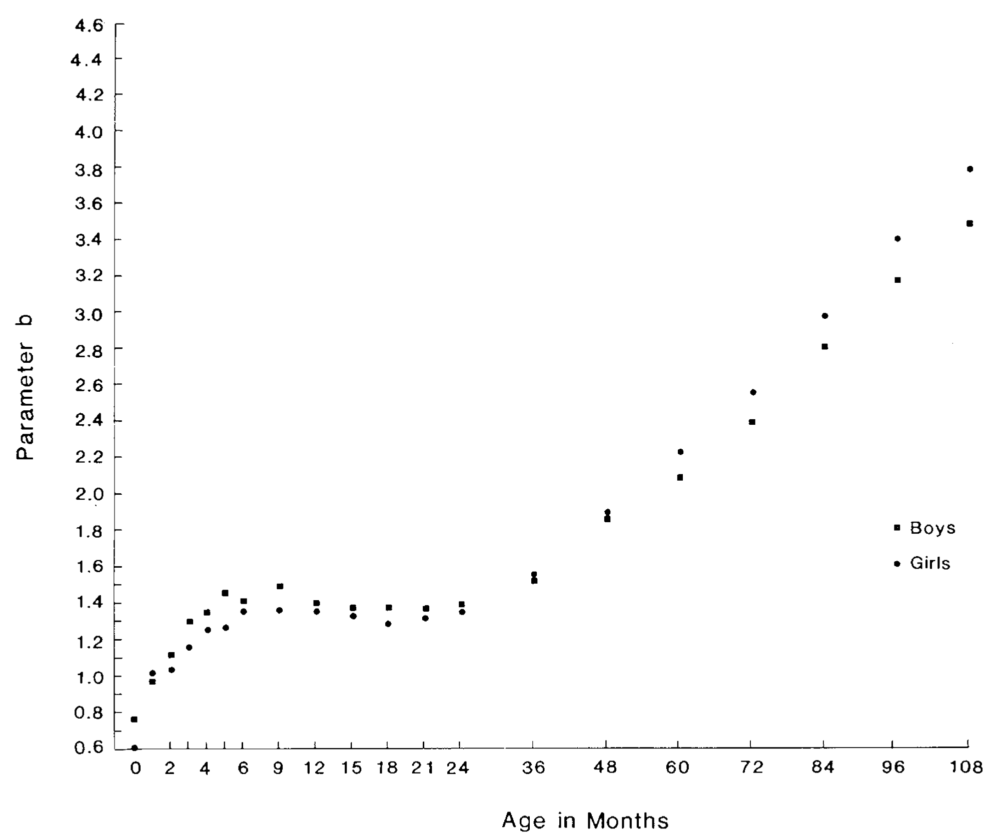

Fig. 3. Values of the parameter b of Benn's formula $b = p\,\bar{w}/\bar{h}$ by sex and by age from birth to 9 years for white healthy children, where b is the slope of the arithmetic regression model of Benn (1).

months ($p = 1.73$), the nadir for girls at 18–21 months ($p = 1.75$). The values for boys rise gradually to 2.69 at 9 years of age and to 3.04 for girls (Figs. 1 and 2, Table 1).

At birth, boys and girls have widely differing values of b, 0.77 and 0.64. By 5 months, the value of b for boys rose to 1.46, declined to 1.37 by 21 months, and gradually rose to 4.34 after 9 years of age (Fig. 3). By 6 months, the value of b rose to 1.36 for girls, remained generally level until age 36 months, and then rose to 4.52 after 9 years of age.

The shifting nature of the p values cannot be appreciated from an inspection of the changes in average height and weight over time (Figs. 1 and 2).

DISCUSSION

During the first 9 years of life, height and weight are constantly increasing. The velocity of gain in height ($\Delta H/\Delta t$) is constantly decreasing (12, 16). The velocity of gain in weight ($\Delta W/\Delta t$) decreases rapidly until age 2 and then increases over the subsequent 9 years (12, 16). The value of p of Benn's power index, W/H^p (1) changes direction twice, increasing for 1 month after birth in girls, and for 5 months in boys, decreasing to a nadir at age 2 years, and increasing steadily thereafter. The increases in p reflect the greater influence of relative weight velocity; decreasing values of p represent the period of growth reflecting the greater influence of relative height velocity.

We have described the numerical values and the changes in the exponent p of the power index W/H^p of Benn (1), the ponderosity index least correlated with height, and b, the gradient between height and weight. By using either index (p or b), comparisons of populations of children, but not individual children, may be made more accurately when assessing factors associated with obesity or relative fatness.

We speculate that the change in p, peaking during the 1st and 5th months of life and then falling, reflects the ending of the influence of the prenatal environment (14, 17), and the emergence of genetic and postnatal environmental factors, primarily growth hormone, insulin, and cortisol. These three hormones are major determinants of the utilization of ingested nutrients (11). We cannot explain the early difference in rate of change of boys and girls.

The fall in p between the neonatal period and the end of the 2nd year of life, reflecting the greater influence of relative height velocity over weight, suggests the predominance of hypothalamic control via secretion of growth hormone-releasing factor and increments in growth hormone (2). After the nadir in p is reached at 18–24 months, the relative predominance of accretion in weight occurs because of the preponderant action of somatomedin and insulin (2).

Previous separate assessment of velocity change of height and weight (12, 16) have not implicated potential changes in the timing of hypothalamic control. Our current observations might serve as a time frame in which to assess variations in hypothalamic activity during accretion of height and weight, and may be two timing points in the series of hypothalamic clocks suggested by Tanner (15).

If there is a critical time in body growth that determines eventual outcome, it may be during this 2–24-month period where tissue hyperplasia is occurring more rapidly than increase in size of cells (11).

Using these values of p may improve the correlation between indirect, Benn index (1), and direct measures (skinfold, densitometric, or isotope dilution) of relative fatness, but assessments of these correlations were beyond the scope of this study.

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