

Weight-for-Height Values and Limb Anthropometric Composition of Tube-Fed Children With Quadriplegic Cerebral Palsy

Chi-Keung Kong, MBChB, FHKAM(Paed)*, and Heung-Sang Stephen Wong, BEd, PhD‡

ABSTRACT. *Objective.* Research has shown that growth retardation among children with quadriplegic cerebral palsy (CP) is often attributed to feeding dysfunction and malnutrition. The study compared weight-for-height values and limb anthropometric composition of nasogastric and gastrostomy tube-fed children with quadriplegic CP with those of orally fed children with quadriplegic CP and normal children, to examine the plausible effects of tube feeding on weight-for-height, fat, and muscle values for children with quadriplegic CP.

Methods. Triceps, anterior mid-thigh, and medial calf skinfold thicknesses and the corresponding circumferences of the right or less affected side were measured. The subjects consisted of 119 normal children and 62 orally fed and 48 tube-fed children with quadriplegic CP. Body weight and height were recorded. For children with CP whose height could not be measured, height was estimated from the ulna length. Weight-for-height z scores, limb skinfold thicknesses, fat areas, skinfold-corrected muscle girths, and muscle areas of the children were compared.

Results. Tube-fed children with CP had normal mean weight-for-height z scores. Weight-for-height z scores of the orally fed children with CP were significantly below those of normal children and tube-fed children with CP. For children with CP, whereas triceps skinfold thickness seemed to predict the mid-upper arm fat area correctly, leg skinfold thicknesses seemed to overestimate the corresponding fat areas. Stepwise multiple regression analysis showed that triceps skinfold thicknesses had good correlation ($r = 0.86$) and the presence of CP had nonsignificant correlation with mid-upper arm fat areas. Multiple regression analysis of fat areas with skinfold thicknesses and the presence of CP, however, showed that CP was correlated negatively (partial correlation of CP: thigh, -0.45 ; calf, -0.53) with thigh and calf fat areas. Although skinfold-corrected mid-upper arm muscle girths of children with CP were quite similar to those of normal children, leg muscle girths were much reduced for both orally fed and tube-fed children with CP. The apparent thickening of leg skinfold thicknesses among children with CP probably was attributable to disproportional leg muscle wasting, with resulting reduced internal circumference of the subcutaneous fat layer. For tube-fed children with CP, skinfold thicknesses and fat areas

were increased significantly, although their leg skinfold-corrected muscle girths and areas remained reduced.

Conclusions. Skinfold thickness may overestimate the fat area in the affected limb with significant muscle wasting for children with CP. The condition was particularly obvious in the leg, where muscle wasting was prominent. Because leg muscles represent approximately one quarter of the normal body weight, low weight-for-height values among children with CP can be caused by leg muscle wasting attributable to disuse atrophy, which is unlikely to be correctable with tube feeding. Tube feeding may improve body weight mainly through fat deposition. *Pediatrics* 2005;116:e839–e845. URL: www.pediatrics.org/cgi/doi/10.1542/peds.2005-1029; *cerebral palsy, growth, nutrition*.

ABBREVIATIONS. CP, cerebral palsy; ANCOVA, analysis of covariance.

Characteristically, children with quadriplegic cerebral palsy (CP) have light body weight and short stature.^{1–3} Their light body weight and short stature are usually attributed to malnutrition, because feeding dysfunction is common among these children.^{4,5} Muscle wasting is a common problem for children with CP. Specifically, arm muscle wasting has been cited as evidence of malnutrition for children with CP.^{5,6} Because muscle wasting is a well-known sign of CP, even in the absence of malnutrition, the validity of using muscle wasting as evidence or measurement of malnutrition in CP may be called into question. Although the major proportion of normal body muscle mass is in the lower extremities,^{7–11} there are no related studies on skinfold-corrected leg muscle girths or areas among children with CP. Tube feeding is a method used to ensure adequate nutrition for children with quadriplegic CP. In our unit, the practice has been to adjust the energy intake for tube-fed children with CP to achieve normal weight-for-height values. The purpose of this study is, by comparing the weight-for-height values and limb anthropometric composition (skinfold thicknesses, fat areas, muscle girths, and muscle areas) of tube-fed children with quadriplegic CP with those of orally fed children with CP and normal children, to examine the plausible effects of tube feeding on weight-for-height, fat, and muscle values for children with quadriplegic CP.

METHODS

The Developmental Disabilities Unit of Caritas Medical Centre of Hong Kong provides residential and rehabilitation services to

From the *Department of Paediatrics, Caritas Medical Centre, Hong Kong, China; and ‡Department of Sports Science and Physical Education, The Chinese University of Hong Kong, Shatin, N.T., Hong Kong, China.

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Reprint requests to (C.-K.K.) Department of Paediatrics, Caritas Medical Centre, 111 Wing Hong St, Shamshuipo, Hong Kong, China. E-mail: ck.kong@hotmail.com

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children with severe cognitive impairment. Many of these children also have quadriplegic CP. For the purposes of the present study, children with quadriplegic CP were identified from the patient register of the Developmental Disabilities Unit. Children with metabolic disorders, genetic diseases, and congenital anomalies were excluded. Body weights were measured with a digital bed scale (Scale-Tronix 2001; Scale-Tronix, Wheaton, IL) and recumbent lengths were determined with a Harpenden digital anthropometer (Holtain, Crosswell, Crymych, Dyfed, Great Britain). Each measurement was taken from the headboard, where the child's head touched, to the child's heels. The recumbent length was used as the body height for children with CP. Right triceps, anterior mid-thigh, and medial calf skinfold thicknesses were measured with Harpenden skinfold calipers (John Bull, British Indicators, St Albans, Herts, United Kingdom), and the circumferences of the right mid-upper arm, mid-thigh, and calf were determined with measuring tape.¹² The right ulna length was measured with a Harpenden digital anthropometer for height estimation, as described previously.¹ For children with side asymmetry, measurements were taken on the less affected side. Growth data for local children were used as normative values for weight-for-height comparisons.¹³ Skinfold-corrected muscle girth (muscle girth = limb girth - [$\pi \times$ skinfold thickness]) were calculated for the mid-upper arm, mid-thigh, and calf.¹⁴ Fat and muscle areas were computed. Children with CP were grouped according to whether they were tube fed or orally fed. Informed consent for measurements was not required, because written consent for clinical assessment had been obtained at the time of admission.

Normal children were recruited from the patients of the hospital or their normal siblings. These patients had been in good health and were treated only for acute illnesses. Standing heights were measured with a wall-mounted digital stadiometer (Holtain) and were used as body heights in analyses. Body weights were measured with a seated electronic digital scale. The regression line for right ulna length and standing height for normal children (height = $[A \times \text{ulna length}] + B$, where A and B are constants) was derived for height estimation for children with CP who could not undergo proper recumbent length measurements. Measurements otherwise were the same as those for children with quadriplegic CP. Because data were being collected continuously from normal children for comparison purposes, data for children who had the same measurements taken as in this study, with the exception of the ulna length, were also included in the comparisons between normal children and children with CP. Measurements of normal children were taken after verbal consent was obtained from the parents.

SPSS version 10.0 was used for statistical analysis. Because the study aimed to relate weight and limb composition to height, all comparisons between children referred to their body heights. Analysis of covariance (ANCOVA) using height as a covariate was used to assess the skinfold thicknesses, fat areas, muscle girths, and muscle areas across different heights between 3 groups of children (2 groups of children with CP and 1 group of normal children). Posthoc tests were performed to identify differences between groups if ANCOVA results were found to be statistically significant. Logarithmic values of skinfold thicknesses and fat areas were used in statistical analyses, because it was expected that these values would be highly skewed.

RESULTS

One hundred thirty-seven children with quadriplegic CP who were either tube fed or orally fed and satisfied the selection criteria were identified from the patient register of the Developmental Disabilities Unit. Because the register was not linked to the hospital patient database and had not been updated for some time, 27 of these 137 children had already been discharged or had died. Of the remaining 110 children, there were 48 tube-fed and 62 orally fed children with CP. Five orally fed children and 4 tube-fed children with CP had dyskinetic CP. Other children had either spastic or mixed-type quadriplegic CP. None of these children had independent ambulatory ability. Measurements were taken for 62 normal children (31 boys, 2.4–17.7 years of age; 31 girls, 2.4–13.5 years of age). Height and ulna length data for these children were used to derive the regression equation of height estimation with ulna length, ie, body height (in centimeters) = $[5.45 \times \text{ulna length (in centimeters)}] + 20.7$ ($r = 0.987$; $P < .001$). The correlation of body height and ulna length was weaker for children with CP ($r = 0.928$; $P < .001$). Body heights of 12 tube-fed and 5 orally fed children with CP were estimated from their ulna lengths. Because the body heights of the children with CP were predominantly within the range of 90 to 150 cm (height range of children with CP: boys, 92.3–152.0 cm; girls, 93.5–150.5 cm), only normal children with body heights in this range were included in the comparison analyses. Fifty-five (27 boys and 28 girls) of the 62 newly recruited normal children and 64 (36 boys and 28 girls) previously measured normal children formed the comparison group (height range of normal children: boys, 90.3–150.0 cm; girls, 90.3–149.7 cm). Their characteristics are shown in Table 1.

There were significant differences in weight-for-height z scores among the 3 groups of children (analysis of variance, $P < .001$). Posthoc tests detected no weight-for-height difference between the normal children and the tube-fed children with CP. Weight-for-height z scores for the orally fed children, however, were significantly below those of normal children ($P < .001$) and tube-fed children with CP ($P < .001$).

Figure 1A shows the results of ANCOVA, using height as a covariate, of the skinfold thicknesses between the 3 groups of children. Except for the calf skinfold thicknesses of girls, all skinfold thicknesses

TABLE 1. Characteristics of the Subjects of the Comparison Groups

	No.	Body Weight, kg	Body Height, cm	Age, y	WHZ	BMI	HZ
Boys							
Normal	63	24.1 ± 7.9	121.8 ± 16.9	7.3 ± 3.0	-0.07 ± 0.73	15.8 ± 1.6	0.16 ± 1.10
CP							
Orally fed	31	20.7 ± 5.8	122.8 ± 16.5	12.4 ± 4.2	-1.08 ± 0.89	13.6 ± 1.8	-4.33 ± 1.96
Tube fed	25	22.1 ± 5.7	117.8 ± 13.0	11.2 ± 3.9	0.07 ± 1.23	15.7 ± 2.0	-3.73 ± 2.20
Girls							
Normal	56	25.3 ± 8.0	124.4 ± 16.6	7.8 ± 2.7	0.04 ± 0.67	15.9 ± 1.6	0.12 ± 0.79
CP							
Orally fed	31	23.0 ± 5.8	129.3 ± 12.9	13.3 ± 3.4	-1.00 ± 1.25	13.6 ± 2.2	-3.35 ± 1.85
Tube fed	23	22.3 ± 7.0	120.5 ± 13.5	11.4 ± 3.3	-0.34 ± 1.09	15.0 ± 2.0	-3.99 ± 2.27

Data are presented as mean ± SD. WHZ indicates weight-for-height z score; HZ, height z score.

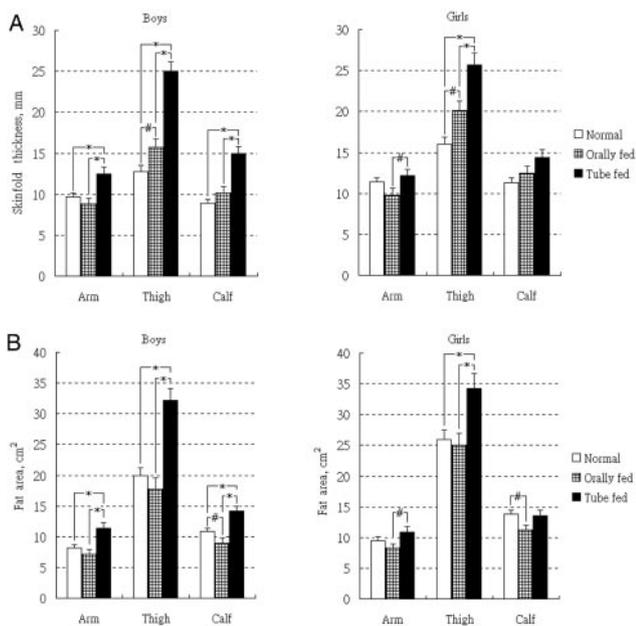


Fig 1. A shows results of ANCOVA of skinfold thickness (mean \pm SE) using height as a covariate, for normal children and children with CP who were either orally fed or tube fed; B, results of ANCOVA of fat areas using height as a covariate. ANCOVA of calf skinfold thickness for girls, $P = .06$; all other ANCOVA, $P < .05$. Logarithmic values were used in statistical significance testing. # $P < .05$, * $P \leq .005$. Limb cross-section area = $\pi \times (\text{limb girth}/2\pi)^2$; muscle area = $\pi \times (\text{skinfold-corrected muscle girth}/2\pi)^2$; fat area = limb cross-sectional area - muscle area.

were found to be significantly different among the 3 groups for both boys and girls. In comparison with normal children, orally fed children with CP seemed to have thinner triceps skinfold thicknesses. The situation, however, seemed to reverse with the measurement of mid-thigh and medial calf skinfold thicknesses. Orally fed children with CP had thicker mid-thigh (boys: $P = .01$; girls: $P = .004$) and medial calf (boys: P value not significant; girls: posthoc test not performed) skinfold thicknesses than did normal children. Tube-fed children with CP had the thickest skinfold thicknesses among the 3 groups, although some of the differences did not reach statistical significance.

Figure 1B shows the results of fat areas of children. Although orally fed children with CP had a significantly thicker mid-thigh skinfold thickness than did normal children, their mid-thigh fat area did not differ significantly from that of normal children. Fur-

thermore, although orally fed children with CP had a slightly and nonsignificantly thicker medial calf skinfold thickness, their calf fat area was found to be significantly smaller than that of normal children. Table 2 shows the results of stepwise multiple regressions of fat areas with corresponding skinfold thicknesses and the presence of CP. Although the presence of CP was not a significant variable for the mid-upper arm fat area, the presence of CP was correlated significantly and negatively with the leg fat areas. The results suggested that leg skinfold thicknesses overestimated the corresponding leg fat areas for children with CP, compared with those for normal children.

Figure 2 shows the scatter plots of the skinfold-corrected muscle girths related to body height. Figure 3 shows the results of ANCOVA, using body height as a covariate, of the skinfold-corrected muscle girths between the 3 groups of children. The mid-thigh and calf muscle girths were smaller for the children with CP, regardless of whether they were orally fed or tube fed. Significantly slightly larger skinfold-corrected mid-upper arm, mid-thigh, and calf muscle girths were found for tube-fed girls, compared with orally fed girls, with CP.

To analyze the effect of body fat on muscle girth, the children with quadriplegic CP were categorized according to their triceps skinfold thickness (<25th percentile, 25th to <50th percentile, 50th to <75th percentile, or ≥ 75 th percentile). Because local normative values for triceps skinfold thickness were available from 6 years of age onward,¹⁵ only children with CP who were ≥ 6 years of age were included in the analysis (50 boys and 52 girls). Their characteristics are shown in Table 3. Eight boys and 22 girls had triceps skinfold thicknesses of <10th percentile. All except the groups with triceps skinfold thicknesses of ≥ 75 th percentile had negative mean weight-for-height z scores. The ANCOVA results for the muscle girths are shown in Table 4. A posthoc test was not performed because the ANCOVA could not detect differences in all 3 muscle girths among the 4 triceps skinfold thickness groups. Muscle and fat areas of the 3 measured sites were summed as the respective total areas and analyzed. The ANCOVA results for the total muscle and fat areas are shown in Fig 4. The total fat area was increased with increasing triceps skinfold thickness percentile. Similarly, ANCOVA

TABLE 2. Stepwise Multiple Regression Analysis of Fat Area With Skinfold Thickness and Presence of CP

	Arm Fat Area		Thigh Fat Area		Calf Fat Area	
	B	Partial Correlation	B	Partial Correlation	B	Partial Correlation
Step 1						
Skinfold thickness	0.91	0.86	1.28	0.85	0.90	0.82
R^2/P		0.73/<.001		0.72/<.001		0.67/<.001
Step 2						
Skinfold thickness			1.46	0.88	1.01	0.87
CP			-6.31	-0.45	-3.29	-0.53
R^2/P				0.78/<.001		0.77/<.001

The probability of F to enter variables was $\leq .05$, and the probability of F to remove variables was $> .1$. Skinfold thickness was the first variable to be entered, followed by CP, for all fat areas. CP was not entered for the mid-upper arm fat area in step 2 of the regression because $P = .43$.

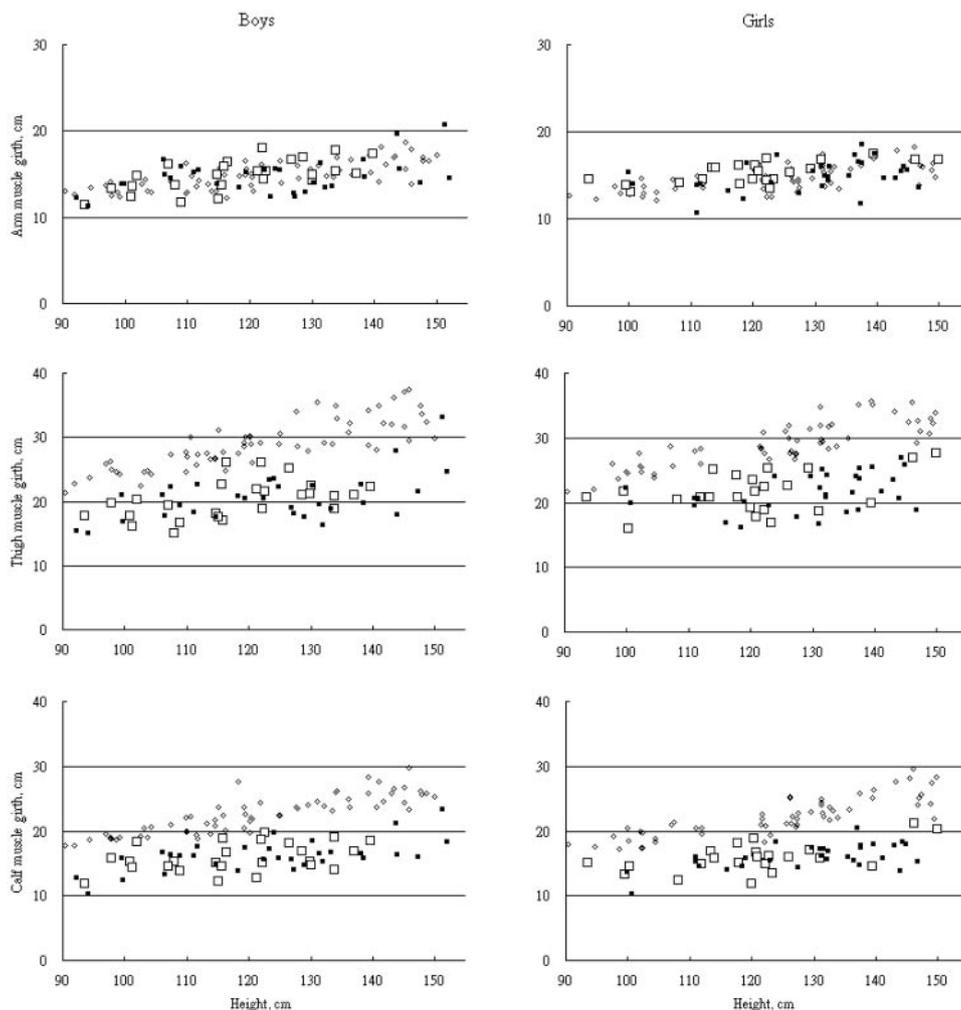


Fig 2. Skinfold-corrected muscle girths in relation to height (\diamond , normal children; \blacksquare , orally fed children with CP; \square , tube-fed children with CP).

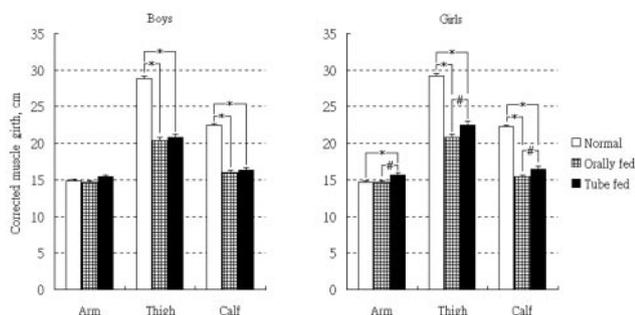


Fig 3. Results of ANCOVA of skinfold-corrected muscle girths (mean \pm SE) using height as a covariate, for normal children and children with CP who were either orally fed or tube fed. # $P < .05$, * $P \leq .005$. ANCOVA of arm muscle girth for boys, $P = .17$; all other ANCOVA, $P < .05$.

could not detect significant differences in total muscle area for boys or girls.

DISCUSSION

Dietitians at the Developmental Disabilities Unit of the Caritas Medical Centre adjusted the tube-fed children's energy intake according to their weight-for-height values. Those with low weight-for-height values were prescribed diets with more energy, with

the intention being for the children to gain weight. The results suggested that the efforts of the dietitians were successful, as indicated by the weight-for-height z score for the tube-fed children, which was close to zero and similar to that for normal children. Previous studies confirmed the positive effect of gastrostomy or nasogastric tube feeding on weight gain among children with CP.^{2,3,16,17} The orally fed children with CP had a significant lower weight-for-height value, compared with normal children and tube-fed children with CP. The observation of growth retardation among children with CP has been well described in previous studies.¹⁸⁻²⁰ Feeding difficulties and inadequate nutrition are common among children with quadriplegic CP, and their failure to thrive is often attributed to malnutrition.^{5,6}

Fat storage is often considered an indicator of nutritional status. Orally fed children with CP had non-significantly thinner triceps skinfold thickness, compared with normal children (Fig 1A). An unexpected result was that the orally fed children with CP had significantly greater mid-thigh skinfold thickness, compared with normal children. The medial calf skinfold thickness also seemed greater for orally fed children with CP. The results for the leg fat areas, however, did not conform to those for skinfold thick-

TABLE 3. Characteristics of Children With Quadriplegic CP Grouped According to Triceps Skinfold Thickness Percentile

Triceps Skinfold Thickness Percentile	No.	Body Weight, kg	Body Height, cm	Age, y	WHZ	BMI	HZ
Boys							
<25th	17	21.4 ± 6.0	124.6 ± 14.9	13.5 ± 2.9	-1.09 ± 0.82	13.8 ± 1.8	-4.53 ± 2.14
25th to <50th	14	19.9 ± 3.6	119.1 ± 13.1	12.0 ± 3.1	-0.64 ± 0.86	14.1 ± 1.77	-4.60 ± 1.15
50th to <75th	11	24.8 ± 5.5	128.9 ± 12.9	13.9 ± 3.9	-0.47 ± 0.96	14.8 ± 2.07	-4.56 ± 2.21
≥75th	8	23.9 ± 5.6	120.8 ± 10.0	11.0 ± 3.5	0.36 ± 1.14	16.2 ± 2.3	-3.17 ± 2.52
Girls							
<25th	31	22.2 ± 5.8	127.9 ± 12.5	13.2 ± 2.8	-1.20 ± 0.81	13.4 ± 1.8	-3.87 ± 2.07
25th to <50th	6	21.4 ± 3.4	121.2 ± 6.1	12.3 ± 2.8	-0.03 ± 1.06	14.7 ± 2.9	-4.13 ± 3.09
50th to <75th	8	23.7 ± 4.8	127.0 ± 13.9	11.9 ± 4.0	-0.5 ± 0.4	14.7 ± 1.0	-2.91 ± 1.68
≥75th	7	27.8 ± 8.8	125.4 ± 17.6	12.4 ± 4.1	0.83 ± 1.56	17.3 ± 2.0	-3.42 ± 1.23

Data are presented as mean ± SD. WHZ indicates weight-for-height z score; HZ, height z score.

TABLE 4. Results of ANCOVA of Skinfold-Corrected Muscle Girths Using Height as a Covariate, for Children With Quadriplegic CP Grouped According to Triceps Skinfold Thickness Percentile

Triceps Skinfold Thickness Percentile	Arm, cm	Thigh, cm	Calf, cm
Boys			
<25th	15.2 ± 0.2	21.1 ± 0.3	16.3 ± 0.2
25th to <50th	15.0 ± 0.4	20.1 ± 0.8	16.6 ± 0.5
50th to <75th	15.0 ± 0.5	21.0 ± 0.9	16.6 ± 0.5
≥75th	15.1 ± 0.6	20.7 ± 1.0	15.7 ± 0.6
Girls			
<25th	15.0 ± 0.2	21.1 ± 0.3	15.9 ± 0.2
25th to <50th	15.5 ± 0.3	21.8 ± 0.5	16.1 ± 0.3
50th to <75th	14.9 ± 0.6	21.7 ± 1.1	16.1 ± 0.7
≥75th	15.5 ± 0.5	23.8 ± 1.0	16.7 ± 0.6

Data are presented as mean ± SE. *P* values for all ANCOVA were nonsignificant.

nesses. The leg fat areas of orally fed children with CP in general were smaller than those of normal children, despite increased skinfold thickness. In a study of healthy male soccer players who had one leg immobilized in a cast for 4 to 5 weeks, Ingemann-Hansen and Halkjaer-Kristensen²¹ found that immobilization induced a significant increase in the subcutaneous thickness and a significant decrease in the circumference of the thigh ($P < .01$). The lean thigh volume decreased significantly but the fat thigh volume was unchanged, resulting in increased subcutaneous thickness. Similar situations might occur among the children with CP because of the disproportional loss of leg muscle mass (Figs 2 and 3). Because of relatively large leg muscle wasting and reduced leg circumference, the skinfold thickness had to increase to contain the relatively well-preserved fat tissue.

Although the mid-thigh skinfold thickness of orally fed children with CP was significantly greater than that of normal children, there was no significant difference in mid-thigh fat areas. Similarly, although the medial calf skinfold thickness of orally fed children with CP seemed thicker than that of normal children, the calf fat area was actually significantly smaller for orally fed children with CP. Results of a negative constant for CP in stepwise multiple regression (Table 2) also suggested discrepancies in the estimation of leg fat areas on the basis of their corresponding skinfold thicknesses for children with CP. Stevenson et al²² found that the triceps, mid-thigh, and calf skinfold thicknesses of the affected side were greater than those of the nonaffected side among children with hemiplegic CP. Although the

differences in the triceps and calf skinfold thicknesses did not reach statistical significance (triceps: $P = 0.198$; calf: $P 0.492$), the difference in mid-thigh skinfold thicknesses was highly significant ($P = .001$). It is probable that the wasting of large thigh muscles exaggerates the increase in thigh skinfold thickness. Muscle wasting decreases the internal circumference of the fat layer; therefore, increased skinfold thickness is required to accommodate the same amount of fat. Results in the present study and similar observations by Ingemann-Hansen and Halkjaer-Kristensen²¹ and Stevenson et al²² support the concept that the validity of skinfold thickness as an assessment of limb fat storage is dependent on the preservation of limb muscles. The results reported by Samson-Fang and Stevenson²³ that suggested good sensitivity and specificity of triceps skinfold thickness for predicting mid-upper arm fat area probably were attributable to good preservation of mid-upper arm muscles among children with CP, as in this study. Consequently, use of skinfold thickness as a measurement, especially for the affected limb, should be used with discretion in the assessment of children with CP, who tend to have muscle wasting.

Although tube-fed children with CP had relatively large limb fat areas, their muscle girths were similar to those of orally fed children with CP and remained significantly smaller than those of normal children. There was no significant difference in muscle girths between oral and tube feeding for boys with CP. Nevertheless, tube-fed girls with CP had significantly slightly larger limb muscle girths than did orally fed girls with CP. After categorization according to triceps skinfold thickness, additional analyses

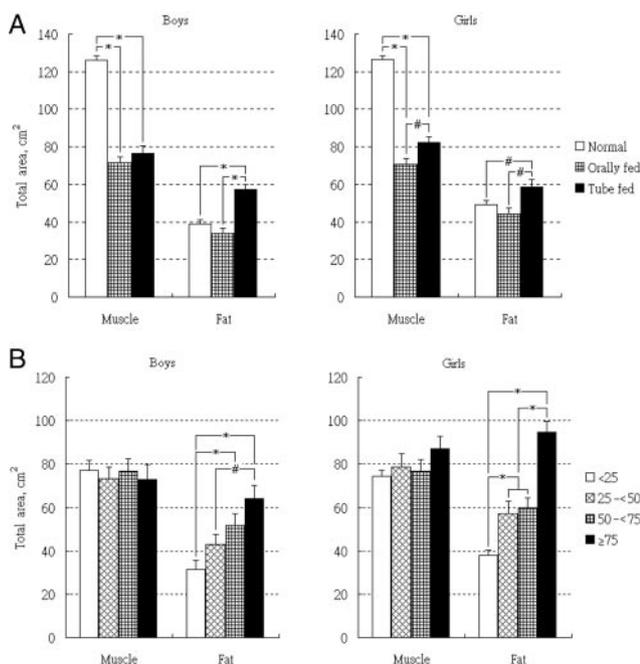


Fig 4. Results of ANCOVA of total muscle and fat area of the 3 measured sites (mean \pm SE) using height as a covariate, for normal children and children with CP who were either orally fed or tube fed (all ANCOVA, $P < .005$) (A) and children with CP after being categorized according to their triceps skinfold thickness percentile (ANCOVA of muscle areas, $P = .93$ for boys and $P = .25$ for girls; ANCOVA of fat areas, $P < .001$ for boys and girls) (B). Logarithmic values were used in statistical significance testing of total fat areas. # $P < .05$, * $P \leq .005$.

were performed on the relationship of muscle to fat among children with CP. These results suggested that, despite increases in fat areas with increased triceps skinfold thickness, there was no obvious associated increase in muscle girths among children with CP. Regarding the slightly increased muscle girths for tube-fed girls with CP, the difference might be too small to be detected after categorization of the children into 4 groups according to their triceps skinfold thicknesses. Although tube feeding might have beneficial effects on muscle wasting, increased muscle girth attributable to intramuscular and intermuscular fat deposition among children with CP also should be considered.²⁴

Despite the fact that our results indicated the effectiveness of tube feeding in maintaining normal weight-for-height values among children with CP, it seems that the normal weight-for-height values could be attributed to fat accumulation. Although triceps skinfold thicknesses of 25th to 75th percentile are probably indicative of adequate energy intake for children with quadriplegic CP, their mean weight-for-height z scores remained below zero (Table 2). It is estimated that nearly one third of our body weight is derived from limb muscles. In particular, the lower limb muscle weight is ~ 3 times that of the arm and represents nearly one quarter of the body weight.⁷⁻¹¹ Consequently, the effect of lower limb muscle atrophy on body weight should not be overlooked. Potentially, leg muscle atrophy could contribute significantly to negative z scores among children with quadriplegic CP.

The results of the present study indicated that the leg muscle girth of children with CP was approximately two thirds of the measurements for normal children (Fig 3). Muscle girth is a one-dimensional measurement, and muscle mass among children of similar heights is dependent on muscle area; this is a two-dimensional measurement. Consequently, this suggests that the leg muscle mass of children with CP was only approximately one half (square of two thirds) that of normal children. Specifically, the loss of leg muscle mass may lead to the loss of approximately one eighth of body weight, because leg muscle weight is approximately one quarter of total body weight. On the basis of the local weight-for-height normative data,⁵ loss of one eighth of body weight in the height range of our subjects implies negative drift of ~ 1 SD in the weight-for-height z score. The effect is more pronounced among younger children. The theoretical z score value of -1 is close to the weight-for-height z score of orally fed children with CP (Table 1), who had fat areas similar to those of normal subjects (Fig 4A). The simulation demonstrates the possible effect of leg muscle wasting on body weight among children with CP. Additional studies may help to clarify whether other nonambulatory children with quadriplegic CP have similar extents of leg muscle loss and weight-for-height changes, compared with the group of children with CP who participated in this study. The results would provide much-needed information, contributing to a greater understanding of low body weight among these children.

The children with quadriplegic CP in this particular study were nonambulatory. It has been speculated that the selective leg muscle loss may be the effect of disuse atrophy. In any situation without the stimulation of weight bearing and walking, leg muscles atrophy; children with CP are no exception. Leg muscle loss was apparent for 8 healthy young volunteers after just 20 days of bed rest.²⁵ No arm or trunk muscle loss was seen. On the contrary, increased (by a few percentage points) arm muscle mass was found. In another study, $\sim 12\%$ of leg muscle mass was lost by 6 male adults after 17 weeks of bed rest.²⁶ Similarly, 3.4% arm muscle gain and no trunk muscle loss were observed. For adults, it was estimated that ~ 0.2 to 0.3 kg of muscle mass were lost, mainly from the legs, per week of bed rest.^{26,27} Clearly, the pattern of relatively preserved arm muscles and atrophied leg muscles among children with CP is very similar to the effects of prolonged bed rest. Brain damage and malnutrition may also lead to muscle wasting among children with CP. There are diverse causes of quadriplegic CP, resulting in equally diverse patterns of brain damage. Therefore, brain damage per se as a cause of consistent disproportional leg muscle wasting, with relative sparing of arm muscles, seems unlikely. Malnutrition should have generalized effects on muscle wasting. Although malnutrition may exaggerate disuse atrophy, it is unlikely to be the primary cause of disproportional leg muscle wasting among children with quadriplegic CP.

This study was a cross-sectional study measuring

limb skinfold thickness and circumference. Realistically, however, a longitudinal study would be more informative, providing data on the muscle and fat changes associated with tube feeding. Interpretations of data obtained in this study need to be treated with caution, because relationships of limb and total-body fat accumulation have not been well studied among children with CP. It is possible that results on limb fat and muscle areas may not be related directly to total body fat and muscle mass. In fact, the gain in total fat area seemed to be too small to compensate for the loss in total muscle area for the weight-for-height z score returning to normal for tube-fed children with CP (Fig 4A). There was probably accompanying fat deposition in truncal areas that was also accountable for the apparent weight improvement of these children. Another limitation of this study is the presence of other structures such as bone, which may also contribute to the weight difference. It was not feasible to include these with the anthropometric measurements in this study.

Despite the limitations of the study, circumstantial evidence seems to suggest that the goal of increasing the weight-for-height values for children with quadriplegic CP to normal may be achieved with an increase in adipose tissue. The effect of tube feeding on leg muscle mass seems limited, considering that the lower limb muscles account for approximately one quarter of normal body weight. Additional studies are needed to develop ways in which energy intake can be manipulated and monitored for optimal growth while avoiding unnecessary fat deposition. Using triceps skinfold thickness instead of weight-for-height percentile and accepting a mildly negative weight-for-height z score may be a more appropriate approach to energy adjustment for children with quadriplegic CP.

CONCLUSIONS

The study shows that the validity of skinfold thickness for predicting fat area depends on preserved integrity of the underlying muscle mass. It seems that triceps skinfold thickness measurements provide useful body fat assessments, because arm muscle mass is better maintained among children with quadriplegic CP. The characteristic leg muscle atrophy found for these children is probably attributable to disuse. This may account for the negative weight-for-height z score. Tube feeding could increase body fat effectively and may be one of the major reasons for weight improvement. It has been shown that lower limb muscle mass remains significantly wasted despite apparent good fat accumulation. Because leg muscle weight represents a significant proportion of the normal body weight, a negative weight-for-height z score may have to be accepted for children with quadriplegic CP. Forcing the weight-for-height z score to or above zero may lead to excessive body fat accumulation.

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