Energy expenditure and physical activity of ambulatory children with cerebral palsy and of typically developing children1–3

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ABSTRACT

Background: Children with cerebral palsy (CP) expend more energy when walking than do their typically developing peers. The effect this has on physical activity levels (PALs) and on total energy expenditure (TEE) will have important implications when determining energy requirements.

Objectives: This study aimed to investigate the components of TEE in children with CP in comparison with typically developing children and to determine what effect the higher energy expenditure during walking has in ambulatory children with CP on PAL and on TEE.

Design: Sixteen children with mild CP and 16 typically developing children, aged 5–12 y, were recruited for the study. Resting energy expenditure (REE) and the energy expenditure during walking were measured by using indirect calorimetry. TEE was determined by using the doubly labeled water technique. PAL was calculated as the ratio of TEE to REE. Body composition was estimated by using oxygen-18.

Results: TEE was lower in children with CP (7012 ± 1268 kJ/d) than in typically developing children (8309 ± 2088 kJ/d) because of a lower PAL (1.57 ± 0.23 compared with 1.79 ± 0.26). The children with CP expended significantly more energy when walking than did the typically developing children (13.8 ± 4.9 compared with 10.3 ± 2.3 kJ/min) while walking at a lower velocity (61 ± 10 compared with 72 ± 8 m/min). Correlations between energy expenditure during walking and PAL were not statistically significant for either group.

Conclusions: Children with CP expend more energy during walking and have a lower PAL and lower energy requirements than do typically developing children. This has important implications when estimating the energy requirements of children with CP. Am J Clin Nutr 2010;92:313–9.

INTRODUCTION

Cerebral palsy (CP) is the most common cause of physical disability in childhood, affecting between 2 and 3 per 1000 neonatal survivors (1). Poor nutrition and growth are frequently reported, and many children with CP are shorter and lighter than similarly aged typically developing children (2–6). Conversely, there is some evidence that overweight and obesity may be common, particularly in those with spasticity and who are relatively inactive (7). Prevention and treatment of both undernutrition and obesity in this group requires a thorough understanding of their nutritional needs and most importantly energy requirements; however, there have been few investigations into the energy requirements of children with CP through measurement of total energy expenditure (TEE) (8–13).

Previous studies that have investigated the energy expenditure of children with CP have been small in scale and used convenience samples. Nevertheless, evidence indicates that the resting energy expenditure (REE) of nonambulatory children with spastic quadriplegic CP is lower than that of typically developing children. This was most likely due to lower fat-free mass (FFM) as a result of participation in less physical activity (8, 9, 11). On the other hand, a small study including 9 ambulatory children and one wheelchair-dependent child with diplegic CP found that the children with CP had levels of FFM similar to those of typically developing children, and the sleeping metabolic rate was not significantly different between the 2 groups (13). Not surprisingly, TEE is lower in nonambulatory children and adolescents with spastic quadriplegic CP than in typically developing children because of lower physical activity levels (PALs) (9, 11). However, the trends are not as clear for ambulatory children with CP. One small study (9) found no significant difference in PAL between ambulatory adolescents with CP and typically developing children, whereas, another study (13) found that ambulatory children with diplegic CP had lower mean PALs than did their typically developing peers.

Ambulatory children with CP expend significantly more energy when walking and walk at a lower self-selected velocity than do healthy typically developing children (14–17). The higher energy expenditure during walking was found to be related to PAL in one small study of 10 children with CP that had no control group (18). In this study, PAL and net oxygen consumption during walking correlated significantly at 2 of 3 predetermined walking speeds. However, this study has many methodologic limitations, including the use of a nonstandardized method for the...
measurement of REE, and the TEE data were derived from the flex heart rate method—a method that has shown some promise at the group level in children with CP but is not suitable for use at the individual level (19).

The aims of the current study were, first, to examine the components of TEE (ie, REE, AEE, and PAL) in children with mild CP in comparison with a control group of their typically developing peers by using gold standard techniques and, second, to determine what effect, if any, the higher energy expenditure during walking has on PAL and TEE. This will have important implications when determining the energy requirements of this group.

SUBJECTS AND METHODS

Ambulatory children [Gross Motor Function Classification System (GMFCS) levels I and II (20)] with diplegia and hemiplegia between 5 and 12 y of age were recruited for the study through the CP League of Queensland and orthopedic and spasticity management clinics at the Royal Children’s Hospital, Brisbane, Australia. Recruitment for this study commenced in 2004. Children were excluded from the study if they used an assistive mobility device (ie, wheelchair or walker; GMFCS levels III, IV, and V), were known to have any chronic illness (eg, cardiac, renal, gastrointestinal, or congenital syndromes), used any medications (eg, steroids) known to affect growth or body composition, had botulinum toxin type A treatment in the previous 6 mo, or had orthopedic surgery within the previous 2 y.

A comparison group of healthy, typically developing children aged 5–12 y was recruited. Siblings and friends of the children with CP were invited to participate, and additional children were recruited through advertisements placed within the Royal Children’s Hospital. Tanner stages were determined by parent report.

Informed consent was obtained from the parents or legal guardians, and the children assented to the procedures. Ethical approval was received from the Human Research Ethics Committees at the University of Queensland, the Royal Children’s Hospital, and the CP League of Queensland. All data were collected within the Queensland Children’s Gait Analysis Laboratory.

Sixteen children with CP and 16 typically developing children were required to identify a 1-SD difference in PAL (ie, 0.23) (20) between the 2 groups as being statistically significant with 80% power and 5% significance. This sample size was also sufficient that a correlation of 0.5 between 2 variables of interest (eg, PAL and energy expenditure during walking) would be statistically significant with 80% power and 5% significance.

Height was measured to the last completed millimeter with a stadiometer (Holtain Ltd, Crymch, Dyfed, United Kingdom). Physical inspection of each child with CP was conducted to determine the presence or absence of contractures and/or scoliosis that could affect the accuracy of the height measurement. Weight was measured to the nearest 100 g by using chair scales (Detecto, Webb City, MO). SD (z) scores for weight and height were determined (21).

Total body water (TBW) was measured by using the stable isotope oxygen-18 in the form of water (H218O) and the back extrapolation method. Details regarding dosing, sample collection and analysis, and calculation of the body water pool are reported below. The oxygen-18 dilution space overestimates TBW by ≈1% because of the contribution of nonaqueous oxygen (21); therefore, TBW was calculated as the oxygen-18 dilution space divided by 1.01. FFM was determined by dividing TBW by age- and sex-specific hydration constants (22, 23).

REE was calculated from data relating to oxygen consumption and carbon dioxide production collected by using the Deltatrac II metabolic monitor (Datex, Helsinki, Finland) as described in detail elsewhere (24). Children fasted for a minimum of 6 h before conducting the REE measurement; during this time they were permitted to consume water only. Because of the age of the subjects and to limit discomfort caused by fasting, the preferred time to conduct the measurements was early morning (eg, 0800). Most of the subjects had fasted for up to 12 h. On arrival at the laboratory, the children sat quietly for a minimum of 30 min before any measurements were taken. After the anthropometric measurements, children were asked to lie quietly in a comfortable position for 30 min while the REE measurement was carried out by using standard procedures (24). To assist with compliance, books were read to the children while they were undergoing this procedure. To ensure that steady state was achieved, the first 10 min of data were eliminated, and the average minute-by-minute values for the following 20 min were used for the analysis. Two subjects became agitated during the measurement, and it became necessary to eliminate the final 10 min of data collected from these children. REE is expressed as kilojoules per day and was determined by using the abbreviated Weir equation (25).

TEE was measured by using the doubly labeled water technique via the multipoint method. Children were given an oral loading dose of oxygen-18 and deuterium in the form of water, dependent on body weight (1.25 g 10% H218O/kg and 0.05 g 100% 2H2O/kg) (26). Considerable care was taken when measuring and recording the dose for each child, and doses were recorded in grams to 2 decimal places. A single baseline urine sample was collected before administration of the dose to determine natural baseline enrichments of the 2 isotopes. A second urine sample was collected ∼5 h after dosing, and a single urine sample was collected daily thereafter for a period of 10 d. Isotopic enrichments of the urine samples were measured by using an isotope ratio mass spectrometer (Hydra isotope ratio mass spectrometer; PDZ Europa, Knutsford, United Kingdom), and the results are expressed relative to the international standard, SMOW (Standard Mean Ocean Water).

Pool sizes for the 2 isotopes were calculated by using standard equations (27). The rate constants were determined by calculating the slope of the regression line relating the natural logarithm of enrichment against time (multipoint method). Carbon dioxide production was determined as the difference in elimination rates between the 2 isotopes, taking fractionation into account (26). Oxygen consumption was calculated assuming a respiratory quotient of 0.85 (28). TEE was calculated according to the abbreviated Weir equation (25).

PAL was calculated for each child as the ratio of TEE of REE (29). AEE was calculated by subtracting REE from TEE after reducing TEE by 10% to account for thermogenesis, ie, AEE = (0.09 × TEE) – REE (29).

The energy expenditure during free walking was calculated from data relating to oxygen consumption and carbon dioxide production collected by using the Cosmed K4b2 (Cosmed, Srl, Italy) as described in detail elsewhere (17). While wearing the
Cosmed apparatus, the children were instructed to 1) sit quietly for 5 min, 2) walk at their usual walking pace constantly around an oval 20-m track for 10 min, and 3) sit quietly for a further 5 min. The time required to complete each lap was recorded by marking the data with the use of the Cosmed software to determine walking velocity (17).

To ensure that the subjects were in steady state for both oxygen consumption and carbon dioxide production during the walking phase, the first 4 min of gas exchange data were eliminated, and the gas exchange data collected from the fifth to the tenth minutes were used for the analysis (17). Energy expenditure during free walking was calculated by using the abbreviated Weir equation (25). The power function, to which body weight was raised to adequately adjust the energy expenditure during walking, for body weight was identified as the slope of the regression line relating natural log energy expenditure during walking to natural log body weight for each group (30, 31).

Data are presented as means ± SDs. For analysis between groups, variables were compared by using independent t tests. For the measurement of the association between 2 variables, Pearson's product-moment correlation analyses were used. To compare the between-group differences in the association of 2 variables, multiple regression analysis was used (30). Statistical analysis was carried out by using the Statistical Package for Social Sciences (SPSS) for Windows (version 11.5; SPSS Inc, Chicago, IL).

RESULTS

Sixteen children with CP (9 boys) participated in this study. Nine children had diplegia and 7 had hemiplegia. All children were independent ambulators: 8 children were classified as GMFCS level I, and 8 were classified as GMFCS level II (20). Three children had well-controlled seizure disorders, one had hydrocephalus with a ventriculoperitoneal shunt, and one child had learning difficulties. All subjects were in otherwise good health. The comparison group consisted of 16 typically developing children (7 boys, 6 of whom were siblings of children in the CP group).

Some basic physical characteristics are shown in Table 1. No statistically significant difference in age was observed between the groups. All children were prepubertal, with the exception of one girl with diplegia and one girl in the control group, both of whom were Tanner stage 2 for breast and pubic hair development.

No statistically significant differences were found between the group of children with CP and the control group for any of the anthropometric or body-composition measures. When separated according to type of CP, again there were no significant differences between the groups for any of these variables.

There were no statistically significant differences in absolute REE (kJ/d) between the children with CP and the control group (Table 2). This trend remained when separated according to diagnosis. As would be expected, statistically significant correlations were found between body weight and REE for all children with CP and the control group. This relation was strongest for the control group (r = 0.89, P < 0.05), as compared with the CP group (r = 0.80, P < 0.05), with body weight accounting for ≈79% and 64% of the variability in REE for the control and CP groups, respectively. In comparison, the variance in REE accounted for by FFM was much less than expected for the children with CP: only 41% (r = 0.64, P < 0.05) compared with 75% (r = 0.87, P < 0.05) for the control group. Nevertheless, the slopes and intercepts for the regression lines relating FFM and REE for the 2 groups were not significantly different (t = −0.06 and t = 0.16, respectively) (Figure 1). These results indicate that there was no significant difference in REE, relative to FFM, between the 2 groups; however, the strength of the relation did differ.

The TEE of the children with CP was significantly less than that for the typically developing children because of a lower AEE (Table 2). There were statistically significant correlations between TEE and FFM for the children with CP (r = 0.74, P < 0.05) and the control group (r = 0.84, P < 0.05). AEE correlated significantly with FFM in the control group (r = 0.65, P < 0.05) but not in the CP group (r = 0.44), which indicated that typically developing children who expend more energy in physical activity per day had a higher FFM, whereas this was not the case for children with CP. As expected, PAL did not correlate significantly with FFM in the CP group (r = 0.27) or in the control group (r = 0.24). Group differences in AEE relative to FFM are graphically shown in Figure 2. No statistically significant difference was found between the slopes of the regression lines relating AEE to FFM (t = −0.53); however, the intercepts were significantly different (t = −2.69, P < 0.05), which indicates that children with CP have a lower AEE, relative to FFM, than do their typically developing peers.

The children with CP expended significantly more energy during walking than did the typically developing children while walking at a significantly lower self-selected velocity (Table 2). The children with hemiplegia expended significantly less energy

<table>
<thead>
<tr>
<th>TABLE 1</th>
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<tbody>
<tr>
<td>Physical characteristics and anthropometric and body-composition measures for children with cerebral palsy and typically developing children†</td>
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<tr>
<td></td>
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<tr>
<td>Age (y)</td>
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<td>Height (cm)</td>
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<tr>
<td>FFM (kg)</td>
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<tr>
<td>FM (kg)</td>
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<td>BF (%)</td>
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</tbody>
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†All values are means ± SDs. FFM, fat-free mass; FM, fat mass; BF, body fat. Between-group comparisons were made by using independent t tests. No statistically significant differences were found between the groups for any of the variables.
During walking than did the children with diplegia. There was no significant difference in walking velocity between the children with diplegia and those with hemiplegia.

Regression lines relating energy expenditure during walking (kJ/min) and FFM for both the children with CP and the control group are shown in Figure 3. Statistically significant differences were found between the slopes of the lines ($t = 2.89, P < 0.05$) and the intercepts ($t = 2.50, P < 0.05$), which indicates that children with CP expend more energy when walking than do their typically developing peers of the same FFM and that this extra energy expenditure increases with increasing FFM.

The slope $\pm$ SE for the regression line relating log energy expenditure during walking to log body weight for the control group was $0.48 \pm 0.26$ and for the CP group was $1.23 \pm 0.16$. Numerically convenient and statistically valid power values, to which body weight was raised to appropriately adjust energy expenditure during walking for this variable, were therefore 0.5 for the control group and 1.2 for the CP group. The relations between PAL and energy expenditure during walking, adjusted for body weight, are shown in Figure 4. This relation was not statistically significant for the children with CP ($r = 0.28$) or for the control group ($r = 0.31$), nor was the relation between TEE and energy expenditure during walking, adjusted for body weight ($r = 0.38$ for the children with CP and $r = 0.30$ for the typically developing children).

**DISCUSSION**

This study had 2 aims: 1) to examine the various TEE components (ie, REE, AEE, and PAL) in ambulatory children with CP in comparison with typically developing children, and 2) to determine what effect, if any, the higher energy expenditure during walking found in ambulatory children with CP has on PAL, TEE, and hence energy requirements. REE was not significantly different between the 2 groups, likely because of the similarities in FFM, and other studies support these results (11, 13). The relation between REE and FFM was weaker for the children with CP than for the typically developing children, potentially because of spasticity and variability in underlying muscle tone among the children with CP. Again, previous researchers have reported similar findings (8, 9). TEE was lower for the children with CP than for the typically developing children because of lower AEEs. The relation between AEE and

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**TABLE 2**

Energy expenditure data for children with cerebral palsy and typically developing children

<table>
<thead>
<tr>
<th></th>
<th>Diplegia ($n = 9$)</th>
<th>Hemiplegia ($n = 7$)</th>
<th>Children with cerebral palsy ($n = 16$)</th>
<th>Typically developing children ($n = 16$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>REE (kJ/d)</td>
<td>$4443 \pm 863$</td>
<td>$4563 \pm 628$</td>
<td>$4498 \pm 703$</td>
<td>$4636 \pm 870$</td>
</tr>
<tr>
<td>TEE (kJ/d)</td>
<td>$6774 \pm 1492$</td>
<td>$7320 \pm 927$</td>
<td>$7012 \pm 1268^2$</td>
<td>$8309 \pm 2088$</td>
</tr>
<tr>
<td>AEE (kJ/d)</td>
<td>$1653 \pm 868$</td>
<td>$2025 \pm 860$</td>
<td>$1816 \pm 858^2$</td>
<td>$2845 \pm 1280$</td>
</tr>
<tr>
<td>PAL</td>
<td>$1.53 \pm 0.22$</td>
<td>$1.62 \pm 0.26$</td>
<td>$1.57 \pm 0.23^2$</td>
<td>$1.79 \pm 0.26$</td>
</tr>
<tr>
<td>Energy expended during walking (kJ/min)</td>
<td>$15.4 \pm 4.7$</td>
<td>$10.2 \pm 3.6^2$</td>
<td>$13.8 \pm 4.9^2$</td>
<td>$10.3 \pm 2.3$</td>
</tr>
<tr>
<td>Walking velocity (m/min)</td>
<td>$60 \pm 11$</td>
<td>$63 \pm 9$</td>
<td>$61 \pm 10^2$</td>
<td>$72 \pm 8$</td>
</tr>
</tbody>
</table>

$^1$ All values are means $\pm$ SDs. REE, resting energy expenditure; TEE, total energy expenditure; AEE, activity-related energy expenditure; PAL, physical activity level. Between-group comparisons were made by using independent $t$ tests.

$^2$ Significantly different from typically developing children, $P < 0.05$.

$^3$ Significantly different from the diplegia group, $P < 0.05$.

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**FIGURE 1.** Resting energy expenditure (REE) as a function of fat-free mass (FFM) for children with cerebral palsy (●, solid line) and typically developing children (○, dashed line). Cerebral palsy ($n = 16$): REE (kJ/d) = $2064 + 128$ FFM (kg), $r = 0.64, P < 0.05$. Typically developing children ($n = 16$): REE (kJ/d) = $2015 + 129$ FFM (kg), $r = 0.87, P < 0.05$. The association between REE and FFM was determined by using Pearson’s product-moment correlation analysis.

**FIGURE 2.** Activity-related energy expenditure (AEE) as a function of fat-free mass (FFM) for children with cerebral palsy (●, solid line) and typically developing children (○, dashed line). Cerebral palsy ($n = 16$): AEE (kJ/d) = $-95 + 101$ FFM (kg), $r = 0.44, P < 0.05$. Typically developing children ($n = 16$): AEE (kJ/d) = $-111 + 146$ FFM (kg), $r = 0.66, P < 0.05$. The association between AEE and FFM was determined by using Pearson’s product-moment correlation analysis.
FFM was weaker in the children with CP than in the typically developing children. In typically developing children, the strength of the relation is related to the mix of weight-bearing and nonweight-bearing activity, with stronger relations in groups of children with more time spent in weight-bearing activity (32). The weakened relation in the children with CP may have been due to less time spent in weight-bearing activity.

AEE and PAL were lowest for the children with diplegia, followed by those with hemiplegia. Because the children with diplegia had both higher energy expenditure during walking and lower walking velocity and those with hemiplegia had only lower walking velocity and not higher energy expenditure during walking, the results suggest that there is a relation between energy expenditure during walking and PAL. However, no statistically significant correlation was found between these variables in either group. Our results appear to be in contrast with those of Maltais et al (18), who found a significant correlation between PAL and net oxygen consumption during walking; however, different methods were used in the 2 studies. Maltais et al (18) reported REE as the average of energy expenditure measurements taken while the subjects were lying, sitting, and standing; TEE was derived from the flex heart rate method, a method that has shown some promise at the group level in developing children. In typically developing children, the different relation between body weight and energy expenditure in children with CP was weaker in the children with CP than in typically developing children and indicates that factors other than weight might be at play. Thigh and lower leg muscle contraction have been reported to account for 51.4% and 42.8%, respectively, of the variability in oxygen consumption/kg body weight, the results of which were consistent with our previous analysis; the correlations between net oxygen consumption/kg and PAL and net oxygen consumption/kg and TEE remained not statistically significant for both groups ($r = -0.21$ and $r = -0.35$ for the typically developing children and $r = -0.15$ and $r = -0.10$ for the children with CP).

A power function of 0.5 was identified for the typically developing children with which to raise body weight to adequately adjust the energy expenditure during walking in this study population. This value is similar to the values previously reported in a large group ($n = 833$) of typically developing children and adolescents (31). Interestingly, for the children with CP, the power function with which to raise body weight was 1.2—a value higher than that previously found for typically developing children. This is reflective of the different relation between body weight and energy expenditure in children with CP than in typically developing children and indicates that factors other than weight might be at play. Thigh and lower leg muscle contraction have been reported to account for 51.4% and 42.8%, respectively, of the variability in oxygen consumption for children with CP (33).

The higher energy expenditure during walking and potentially during other weight-bearing activities in children with CP has many
important clinical implications. PAL is typically used as a multiple of REE to estimate energy requirements, as recommended by the FAO/WHO/UNU in 1985 (34). To do this, PAL is often estimated through a detailed history of the child’s typical physical activity participation (35). Interestingly, the mean PAL for the typically developing children (1.79) was representative of moderate-to-heavy activity (1.70–1.95) according to internationally recognized criteria (36), whereas that for the children with CP (1.57) was closest to light activity (girls: 1.50; boys: 1.55). Superficially, it appears that the internationally recommended values for PAL are suitable for use in ambulatory children with CP; however, because the children with CP have a higher energy expenditure during walking at a lower walking velocity, the reduction in physical activity per se must be greater than would be suggested by the differences in PAL. Furthermore, increases in daily patterns of physical activity, as often recommended for the prevention and treatment of obesity, may increase TEE by a greater amount in children with CP than in typically developing children. Any small changes to physical activity participation may result in large changes to energy requirements. This area requires further investigation.

Note that, as shown in Figures 1 through 3, one typically developing child had an FFM that was significantly greater than that of the remainder of the group, thereby potentially increasing the correlations between FFM and the various energy expenditure components disproportionately for the typically developing children as compared with the children with CP. Indeed, once this child was removed from the analysis, the correlations were lower for the relations between REE and FFM (r = 0.75, P < 0.05) and AEE and FFM (r = 0.34), but higher for the relation between energy expenditure during walking and FFM (r = 0.81, P < 0.05). Removal of the outlier made no significant difference to the regression equations relating FFM to REE, AEE, or energy expenditure during walking. Furthermore, there was no valid reason for removing these data from the statistical analysis because we were unable to find any inaccuracies in the raw data.

There was no significant difference in height between the children with CP and the typically developing children in this study. This is unusual, because children with CP are frequently reported as being shorter and lighter than their typically developing peers (2–6). Our findings can be explained by 2 factors: the mild severity of CP and the good nutritional status of the group, as previously reported (37). These results are not unique, because at least one previous study reported no statistically significant differences in height and weight between ambulatory children with spastic diplegia and healthy control subjects (13).

In conclusion, this study confirmed that children with mild CP expend significantly more energy during walking than do their typically developing peers and have a lower PAL, TEE, and, hence, energy requirement when compared with typically developing children. These results indicate that a significant relation between energy expenditure during walking and PAL may exist; however, they cannot confirm this. Further research is required to investigate the effect of interventions that aim to increase daily patterns of physical activity, as frequently recommended for the prevention and treatment of obesity, on PAL and TEE in children with CP. This will have important implications when estimating the energy requirements of children with CP.

We thank the CP League of Queensland and the Queensland Paediatric Rehabilitation Service for assisting in the recruitment of subjects, the Queensland Children’s Gait Analysis Laboratory for providing a venue for data collection and technical support, the Royal Children’s Hospital Foundation for financial support, and Kelli Edmiston and Connie Wishart for the urine sample analysis.

The authors’ responsibilities were as follows—KLB and PSWD: designed the study protocol and contributed to the critical review and interpretation of data and writing of the manuscript; and KLB: recruited the subjects, conducted all measurements, documented the data, performed the statistical analysis, and coordinated the study under the supervision of PSWD. Neither author had a potential conflict of interest.

REFERENCES