Validation of a New Handheld Device for Measuring Resting Metabolic Rate and Oxygen Consumption in Children

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The purpose of this study was to assess the validity and reliability of the MedGem™ device to measure resting metabolic rate (RMR) in children. Subjects included 59 children (29 boys, 30 girls; mean age, 11.0 ± 0.2 y). Subjects were given 4 RMR tests during 1 test session, consisting of 2 Douglas bag and 2 MedGem tests, in random counterbalanced order. No significant differences were found between Douglas bag and MedGem systems for oxygen consumption (209 ± 5 and 213 ± 5 mL/min, respectively, \( P = 0.106, r = 0.911 \), mean ± standard deviation absolute difference 3.72 ± 17.40 mL/min) or RMR (1460 ± 39 and 1477 ± 35 kcal/d, \( P = 0.286, r = 0.909 \), mean ± standard deviation absolute difference 17.4 ± 124 kcal/d). Standard error of estimates for oxygen consumption and RMR were 17.4 mL/min and 124 kcal/d, respectively. In conclusion, these data indicate that the MedGem is a reliable and valid system for measuring oxygen consumption and RMR in children.

Key Words: oxygen consumption, metabolism, energy expenditure

The prevalence of overweight among American youth has tripled since the 1960s from 4.4% to 15.4% (18, 22). Management of overweight in young children has been described as the best strategy for confronting the nationwide epidemic of childhood obesity (1, 12). Measurement of total daily energy expenditure and resting metabolic rate (RMR) has improved our understanding of the pathophysiology of human obesity and, although currently underused, has the potential to improve management of obesity in children (6).

RMR in children can be measured using human calorimeters, closed-circuit indirect calorimetry equipment, and open-circuit indirect calorimetry equipment such as Douglas bags and gas analyzers, whole-body respiratory chambers, and computerized metabolic carts (6, 11). These methods are costly and cumbersome to conduct, require highly skilled technicians, and are impractical for most clinical and community settings. Pediatric RMR prediction equations have been developed using variables such as age, stature, and body mass (7, 8, 11, 19, 20, 27). Unfortunately, only 52% to 89% of the variability in RMR is explained by these equations (8, 11), and they systematically misclassify children who are obese, of minority ethnic background, and diseased or critically ill (4, 5, 9, 10, 14, 15, 19, 23-27). Thus the estimation of RMR in children induces substantial error and is
not applicable to special populations. Most investigators recommend that RMR be measured in children whenever possible to reduce the risk of misclassification and errors regarding estimation of energy intake and balance (4, 5, 9, 25).

For these reasons, there is a need for an inexpensive, easy-to-use, portable, and accurate device for measurement of resting energy expenditure in nonlaboratory settings. A small, handheld device for measuring human resting metabolism was developed (first prototype introduced in 1998) to allow the accurate and practical assessment of RMR in a variety of settings (BodyGem™ and MedGem™; HealtheTech, Inc., Golden, CO; the BodyGem is a device available to the general health and fitness professional, and the MedGem is a FDA-cleared Type II medical device.). Individuals hold the unit while breathing through an attached mouthpiece or facemask for 5 to 12 min, and sensors measure oxygen consumption, ventilation, temperature, humidity, and barometric pressure before providing a digital readout of RMR in kcal/d.

In a validation study with 63 men and women ranging widely in age and body-mass index, the BodyGem gave reproducible and valid RMR measurements when compared with the Douglas bag method, with a standard error of estimate (SEE) of 134 kcal/d (17). Two other validation studies indicate that the BodyGem and MedGem provide RMR estimates that are comparable to a metabolic cart (16) or the Delta-Trac (SensorMedics, Yorba Linda, CA) (21). FDA approval for RMR measurement using the MedGem was specified for tidal volumes of 500 mL/breath and higher, although sensors within the unit give RMR measurements when tidal volumes are 200 mL/breath and higher (technical report, HealtheTech, Inc.). Tidal volumes of children are lower than those measured in adults, and the purpose of this study was to determine the MedGem unit’s validity and reliability in measuring RMR when compared with the Douglas bag method in a pediatric population.

Subjects and Methods

Subjects

White subjects between the ages of 7 and 13 y were recruited from the surrounding community through advertisement. Testing procedures were approved by the university’s institutional review board before the beginning of the study, and subjects and their parents voluntarily gave consent.

Design

Subjects were given 4 separate RMR tests during 1 test session, and consisted of 2 Douglas-bag and 2 MedGem tests, in random counterbalanced order. Test sessions were at the same time of the day (3:00 to 5:00 PM) to reduce the effect of diurnal variation. Subjects avoided energy intake and strenuous exercise for at least 3 h before testing. It should be understood that the basal metabolic rate (BMR) is the rate of energy expenditure for an individual at rest in a supine position, measured immediately after at least 8 h of sleep and 12 h of fasting. Most investigators now use the term resting metabolic rate when measurements follow altered conditions required for measuring BMR. In this article, RMR refers to measurements taken in the late afternoon in seated subjects who have avoided energy intake for at least 3 h.
Stature and body mass were measured, and body composition was estimated through a 2-site skinfold test (triceps and subscapular) (13). After completion of anthropometric measurements, subjects sat quietly for 10 min and were given orientation to the testing procedures before the 4 RMR measurements. Subjects remained seated for the duration of the testing period, awake, and relaxed. Each RMR measurement was of 12 min duration, and subjects were given a 2- to 3-min seated break between tests.

**Douglas Bag Testing Procedures**

Douglas bag collections of expired gases were made for 10 min using a mouthpiece connected to a Hans-Rudolph small 2-way valve (Hans-Rudolph, Inc., Kansas City, MO) and noseclip. Subjects were connected to the collection apparatus for 2 min before gas collection was started to ensure that all dead space in the valves and tubing was flushed with expired gas. Expired gas fractions were analyzed using an Applied Electrochemistry S-3A oxygen analyzer and an Applied Electrochemistry CD-3A carbon-dioxide analyzer (AEI Technologies, Applied Electrochemistry, Pittsburgh, PA). The analyzers were calibrated using a 2-point method with outside air and medical-grade primary standard gases containing 16.0% O$_2$ and 4.0% CO$_2$ (Matheson Tri-Gas, Parsippany, NJ). Expired gas volumes were measured using a Rayfield RAM 9200 airflow meter (Rayfield Equipment Co., Waitsfield, VT) calibrated against a Tissot spirometer. RMR in kcal/d was estimated using the de V Weir equation (2):

$$RMR \text{ (kcal/d)} = 5.675 \times VO_2 + 1.593 \times VCO_2 - 21.7$$

where VO$_2$ and VCO$_2$ are in mL/min.

**MedGem Testing**

The MedGem is designed for use as a stand-alone device and displays the RMR in kcal/d on a liquid-crystal display at the conclusion of the test. For the purpose of this study, additional data were required, so that the MedGem was connected to the serial port of a computer for downloading of data files that included information on oxygen consumption and RMR. The MedGem units were autocalibrated before each test (a 5-s interval during which the flow sensors are set). During the test, a noseclip was used, and subjects breathed into the MedGem for 10 min through a mouthpiece while holding the unit level, elbow propped against an arm rest. Sensors measured humidity, temperature, and barometric pressure for use in internal calculations. Oxygen concentration in the inspired and expired airflow is measured by a proprietary dual-channel fluorescent quenching sensor. The principle of operation is based on the deactivation of ruthenium in the presence of oxygen. A ruthenium cell is excited by an internal light source and fluoresces. This reaction is quenched by the presence of oxygen, and the amount of quenching is proportional to the concentration of oxygen. This sensor has a rapid, 50-ms response time, and the oxygen concentration in the flow path is sampled at 10 Hz. The volume of inspired and expired air is measured using ultrasonic sensing technology. There is a transducer at each end of the flow tube that emits a sound pulse. The transmission time from the sending to the receiving transducer is increased or decreased in
proportion to the rate and direction of gas flow. These sensors work at a rate of 100 Hz. The MedGem uses standard metabolic formulas to calculate oxygen uptake. RMR is calculated from oxygen consumption, a fixed respiratory quotient of 0.85, and grams of urinary nitrogen calculated from mean energy and protein intake of US males and females using a modified Weir equation:

\[
\text{RMR (kcal/d)} = (3.941 \times \text{VO}_2) + (0.85 \times 1.106 \times \text{VO}_2) - (2.17 \times \text{gm urinary nitrogen})
\]

where \(\text{VO}_2\) is in L/d and \(\text{gm urinary nitrogen} = [(\text{kcal/d} \times 0.16)/4]/6.25\).

Previous testing with 22 MedGems tested 7 times over 3 d using a mechanical metabolic simulator determined that the coefficient of variation for repeated testing is 1.45% with an intraclass reliability coefficient of 0.98 (personal communication, 7/1/04, HealtheTech).

**Statistical Analysis**

Statistical significance was set at the \(P < 0.05\) level, and values were expressed as mean ± standard error. Values from the 2 tests were averaged and compared between methods using paired \(t\)-tests and Pearson product-moment coefficients, with a Bland-Altman plot used to show the difference scores between methods (Douglas bag – MedGem) over the complete range of measured RMR (21). Standard estimates of error (SEE) were calculated with this equation: \(\text{SEE} = \text{SD}_{\text{DB}} \sqrt{1 - r^2}\) (\(\text{SD}_{\text{DB}}\) = the standard deviation from the Douglas bag test data). Within-test-session reliability was calculated using intraclass correlation coefficients.

**Results**

Fifty-nine subjects (29 boys, 30 girls) completed all phases of the study. Subject characteristics are reported in Table 1, with data summarized for age, body mass, stature, body-mass index (BMI), and percentage body fat. Age ranged from 7 to 13 y, with 40% of the subjects 7 to 10 y of age and 60% 11 to 13 y of age. No difference was found between boys and girls for all variables measured except for percentage body fat (21.8 ± 1.7 and 26.7 ± 1.5%, respectively, \(P = 0.037\)). Thus

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean ± standard error</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>11.0 ± 0.2</td>
<td>7–13</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>44.9 ± 2.0</td>
<td>22.5–108.0</td>
</tr>
<tr>
<td>Stature (m)</td>
<td>1.47 ± 0.02</td>
<td>1.14–1.70</td>
</tr>
<tr>
<td>Body-mass index (kg/m²)</td>
<td>20.1 ± 0.6</td>
<td>14.6–38.4</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>24.2 ± 1.2</td>
<td>9.0–49.0</td>
</tr>
</tbody>
</table>

*Note. N = 59; 29 boys, 30 girls.*
data are presented for all subjects combined. BMI ranged from 14.6 to 38.4 kg/m², with 58% of the children having a BMI < 20 kg/m², 30% of children 20 to 24.9 kg/m², and 12% ≥ 25 kg/m².

Metabolic measurements from the Douglas bag system for all subjects combined are summarized in Table 2. Weight-adjusted oxygen consumption ranged from 2.65 to 6.84 mL · kg⁻¹ · min⁻¹. Tidal volume ranged from 232 to 623 mL/breath. Temperature, barometric pressure, and humidity measurements averaged 23.0 ± 0.1 °C, 677 ± 3 mmHg, and 32.2 ± 0.8%, respectively, during the test sessions.

Oxygen consumption and RMR data from the Douglas bag and MedGem systems for tests 1 and 2 are compared in Table 3. The test-to-test reliability correlation coefficient for oxygen consumption for the MedGem was $r = 0.94$, and for the Douglas bag method, $r = 0.95$. No significant differences in oxygen consumption or

### Table 2  Metabolic Measurements from the Douglas-Bag System (DB) and MedGem (GEM) for all Subjects Combined

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean ± standard error</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ventilation (L/min, DB)</td>
<td>7.1 ± 0.2</td>
<td>4.4–14.1</td>
</tr>
<tr>
<td>VCO₂ (mL/min, DB)</td>
<td>185 ± 5.0</td>
<td>124–288</td>
</tr>
<tr>
<td>Respiratory exchange ratio (DB)</td>
<td>0.88 ± 0.01</td>
<td>0.79–1.03</td>
</tr>
<tr>
<td>VO₂ (mL · kg⁻¹ · min⁻¹, DB)</td>
<td>4.91 ± 0.12</td>
<td>2.65–6.84</td>
</tr>
<tr>
<td>Respiratory rate (breaths/min, GEM)</td>
<td>17.1 ± 0.4</td>
<td>10.9–23.8</td>
</tr>
<tr>
<td>Tidal volume (mL/breath, GEM)</td>
<td>381 ± 12</td>
<td>232–623</td>
</tr>
</tbody>
</table>

*Note.* Values are means ± standard error from 2 measurements.

### Table 3  Oxygen Consumption and Resting Metabolic Rate from Tests 1 and 2 from the Douglas Bag System and MedGem for All Subjects Combined

<table>
<thead>
<tr>
<th>Variable</th>
<th>Test 1</th>
<th>Test 2</th>
<th>Correlation coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Douglas bag system oxygen consumption</td>
<td>209 ± 6</td>
<td>210 ± 5</td>
<td>0.95</td>
</tr>
<tr>
<td>resting metabolic rate (kcal/d)</td>
<td>1453 ± 40</td>
<td>1467 ± 38</td>
<td>0.95</td>
</tr>
<tr>
<td>MedGem oxygen consumption (mL/min)</td>
<td>211 ± 5</td>
<td>215 ± 5</td>
<td>0.94</td>
</tr>
<tr>
<td>resting metabolic rate (kcal/d)</td>
<td>1464 ± 34</td>
<td>1491 ± 37</td>
<td>0.94</td>
</tr>
</tbody>
</table>

*Note.* $N = 59$
RMR were found for tests 1 and 2 between the Douglas bag and MedGem systems (Table 3). Oxygen consumption and RMR data (mean of 2 tests) from the Douglas bag and MedGem systems are compared in Figure 1. No significant differences were found between Douglas bag and MedGem systems for oxygen consumption ($P = 0.106$, $r = 0.911$, mean ± standard deviation absolute difference $3.72 ± 17.40$ mL/min) or RMR ($P = 0.286$, $r = 0.909$, mean ± standard deviation absolute difference $17.4 ± 124$ kcal/d). RMR difference between MedGem and Douglas bag systems did not vary significantly across the age range of this group ($r = –0.01$, $P = 0.475$), but a small part of the variance was related to BMI ($r = 0.37$, BMI = 0.002). Standard error of estimates for oxygen consumption and RMR were $17.4$ mL/min and $124$ kcal/d, respectively.

A Bland-Altman plot was used to show the difference scores between methods (Douglas bag – MedGem) over the complete range of measured RMR (Figure 2). The correlation between the mean estimation and the difference in estimation of RMR between the Douglas bag and MedGem systems was $r = 0.24$, $P = 0.036$. This indicates a slightly greater difference in RMR estimation between systems at the lower and higher RMR levels.

**Discussion**

These data indicate that the MedGem is a reliable and valid system for measuring oxygen consumption and RMR in boys and girls ranging in age from 7 to 13 y. Treatments were randomized and counterbalanced so that one-half of the children performed the Douglas bag test first while the other half performed the MedGem trial first. No significant difference in RMR measurement was found between Douglas bag and MedGem systems, and the SEE of $124$ kcal/d is comparable to what we
have previously reported in adults (17). This variation may have been smaller had the research design included simultaneous sampling of expired air. The MedGem is not equipped, however, for simultaneous measurement with other devices. The MedGem includes an oxygen analyzer, estimating RMR by assuming a respiratory quotient of 0.85. This assumption introduces little error, however, in estimating RMR, as verified in our earlier validation study with adults (17).

The test-to-test reliability correlation coefficient for oxygen consumption for the MedGem was high ($r = 0.94$), and similar to that for the Douglas bag method ($r = 0.95$). This indicates that RMR measurement using either system is highly reproducible, and that a single measurement is sufficient in clinical, research, or fitness club settings. Other investigators have also reported that the intraindividual variation in RMR measurement is low in pediatric populations when the test environment is carefully controlled (3).

This study was not designed to compare RMR measurements from the Douglas bag system with pediatric RMR estimating equations (5, 8). We measured RMR in the late afternoon while the children sat in a quiet, laboratory controlled environment. The research design allowed us to compare the Douglas bag and MedGem systems, but the absolute RMR values were substantially higher than the basal metabolic rate levels estimated by the Harris–Benedict equations (7) (136 ± 19 kcal/d difference between Douglas bag and HBE) or the Institute of Medicine equations (11) (87 ± 22 kcal/d difference).
These results support the use of the MedGem for measuring RMR in children in nutritional, clinical, and weight-management settings. Tidal volumes ranged from 232 to 623 mL/breath, verifying that the MedGem functions well at the lower tidal volumes seen in children. Subjects in this study were white, and further validation testing is needed in children of varying ethnic backgrounds (10). We found a slightly greater difference in RMR estimation between systems at the lower and higher RMR levels, but this difference was small and appears to have been related to several outlier measurements.

Pediatric RMR prediction equations using stature, body mass, and age introduce considerable error, and this might, in part, be genetically determined (6). Thus, estimating RMR from equations has limited predictive value for the individual child, and their use is not recommended when providing energy intake counseling (4, 9, 26). Indirect calorimetry from computerized metabolic carts provide accurate RMR assessments for pediatric patients in clinical settings, but this method requires highly skilled technicians and expensive equipment. Our findings indicate that the MedGem provides a quick and convenient estimate of RMR in children that is accurate and reliable, and should facilitate the process of pediatric weight-management counseling.

Acknowledgments

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References