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Comparison of Two Systems for Measuring Energy Expenditure

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Comparison of Two Systems for Measuring Energy Expenditure

A STUDY IN INDIRECT CALORIMETRY

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ABSTRACT

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Health care professionals typically use resting metabolic rate (RMR) via indirect calorimetry to determine a person’s energy expenditure. RMR via indirect calorimetry is determined by either by oxygen consumption (VO$_2$) or oxygen consumption and carbon dioxide production (VCO$_2$). Traditional indirect calorimetry measurements involve an expensive, heavy piece of equipment that requires careful calibration. The recent development of a handheld indirect calorimeter makes it easier to measure RMR at a lower cost. Few investigators have compared the effectiveness of the new handheld device to traditional indirect calorimetry equipment. PURPOSE: To validate the accuracy and precision of the handheld indirect calorimetry device by simultaneously comparing its measurements to those from a traditional indirect calorimeter.

METHODS: Healthy, free-living subjects (n=50), ages 18 years and older, were tested simultaneously with both indirect calorimeters. All subjects breathed through the handheld device using a mouthpiece and noseclips were applied to prevent leaks. The handheld indirect calorimetry device was placed inside a canopy with the exhaled gas from the handheld positioned directly over the inlet to the port delivering gases to the traditional device’s mixing chamber. All expired gases were simultaneously collected into the traditional device via a canopy. During the measurement, VO$_2$ and RMR were continuously recorded to a personal computer.

RESULTS: Mean oxygen consumption and RMR did not significantly differ between the two devices, with a mean difference of $0.58 \pm 15.33$ ml per min$^{-1}$ ($p = 0.790$) and $4.66 \pm 113.39$ kcal per day$^{-1}$ ($p = 0.773$) and an absolute difference of $12.3 \pm 8.99$ ml per min$^{-1}$ and $86.58 \pm 72.32$ kcal per day$^{-1}$,
respectively. Correlation coefficients for oxygen consumption and RMR were 0.945 and 0.941, respectively. **CONCLUSION:** No significant difference was found between the measurements obtained from both indirect calorimetry devices. These findings suggest that the handheld indirect calorimetry device provides an accurate and reliable measure of oxygen consumption and RMR measurements for spontaneously breathing subjects.
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Introduction

Appropriate nutrition promotes weight management, effective healing, normal body function, and the prevention of chronic disease. The importance of appropriate nutrition becomes substantially greater with an acute illness or injury. Malnutrition in a clinical setting is associated with poor treatment outcomes and increased mortality.\textsuperscript{1,2} Accurate nutritional assessment is essential for proper nutritional support in a clinical setting. To assess a patient’s daily kilocalorie needs, health professionals typically use the Harris-Benedict equation to estimate a patient’s predicted resting metabolic rate (RMR).\textsuperscript{3} The Harris-Benedict equation considers the patient’s weight, height, age, and sex to determine energy needs. Predictive equations have been shown to be unsystematically incorrect and may vary by 70 to 140\% when compared to actual caloric needs. In the clinical setting, this results in inappropriate feeding.\textsuperscript{4,5} Using RMR as a measurement of energy expenditure allows dietetics professionals to prescribe an individual nutrition prescription for hospitalized patients.\textsuperscript{5} Body composition, physical activity habits, race/ethnicity, and condition-related metabolic disturbances affect RMR and cannot be factored in as a part of the predicted value.\textsuperscript{6,7,8,9}

Health care professionals measure RMR via indirect calorimetry by either oxygen consumption (VO\textsubscript{2}) or oxygen consumption and carbon dioxide production (VCO\textsubscript{2}). The traditional indirect calorimeter is an expensive ($\geq$25,000), heavy piece of equipment that requires careful calibration, making routine measurement outside the intensive care unit difficult and impractical.\textsuperscript{10} These limitations suggest a need for an inexpensive,
portable device to measure RMR in healthcare settings. The recent development of a handheld device now makes it possible for health care professionals to easily measure RMR.\textsuperscript{11} The MedGem handheld indirect calorimeter enables practitioners to assess patients’ RMR at a relatively low cost. The MedGem RMR analyzer costs $2500, weighs < 1 pound, and has 510K designation by the FDA. However, few investigators have compared the effectiveness and efficacy of this new device to traditional indirect calorimetry equipment.\textsuperscript{12} The purpose of this study was to validate the accuracy and precision of the MedGem device by simultaneously comparing its measurements to those from a traditional indirect calorimeter. Specifically, this is the first study that simultaneously compares the measurement of VO\textsubscript{2} and RMR with the MedGem and the DeltaTrac, a well-studied and validated traditional open circuit indirect calorimeter based on the dilution principle.\textsuperscript{13,14}

**Methods**

**Subjects**

Free-living, healthy subjects 18 years old and older were recruited by posting an advertisement about this study throughout the University of Cincinnati Medical Center. The University of Cincinnati Medical Center Institutional Review Board approved the study. Power calculations determined the number if subjects needed to determine a statistically significant difference between the RMR measurements of the two devices to be 25. More subjects were included due to a high level of interest during recruitment and non-invasive nature of the procedures. Prior to study initiation, the investigators trialed the simultaneous measurement procedure to assure proper function and comfort.
Before performing any of the study procedures, researchers obtained written informed consent from each subject. Fifty-two people volunteered to participate in the study. Two subjects did not attend the study appointment and were dropped from the study. Fifty subjects were tested simultaneously with both the DeltaTrac and MedGem indirect calorimeters. Demographic information including age, gender, and race/ethnicity was collected from each subject. Testing occurred during a single visit between 6:30am and 10:00am. Morning hours were selected to allow subjects greater ease for fasting. The subjects refrained from exercise for 24 hours prior to the testing and fasted for 12 hours prior to the testing. Exercising and consuming food and beverages prior to testing may falsely elevate the measurement.

Procedure
Each subject's height and weight were measured using a stadiometer and beam balance scale (DetectoMedic, Brooklyn, New York). Prior to the testing, subjects reclined quietly in a chair for 5 to 10 minutes, to stabilize their breathing and heart rate. The MedGem was placed inside the canopy with the exhaled gas from the MedGem positioned directly over the inlet to the port delivering gases to the DeltaTrac’s mixing chamber. All subjects breathed through the MedGem using a disposable, scuba-type mouthpiece and noseclips were applied to prevent leaks. In order for the subjects’ arms to remain at their sides, the MedGem monitor was held in place with a clamp at the end of an extension rod. Previous work by Melanson, et al. demonstrated an increase in RMR of approximately 5% associated with subjects holding the MedGem in one hand.\textsuperscript{15}
All expired gases were simultaneously collected into the DeltaTrac monitor via a canopy. The measurement time was 10 minutes because the MedGem is designed to stop testing after a 10-minute period or when a steady state of breathing is achieved. The subjects were instructed to remain relaxed and to breathe normally throughout the testing. During the measurement, VO$_2$ and RMR were continuously recorded to a personal computer. In order to gauge subject comfort, heart rate and oxygen saturation was continuously monitored via pulse oximetry.

**MedGem**

Prior to each test, the MedGem performs an automatic calibration (a 5-second time period during which the ultrasonic flow sensors are set) and eliminates the first two minutes of breathing prior to beginning a minute-to-minute measurement of RMR. At the conclusion of the test, the device displays the RMR and the oxygen consumption. To download each subject’s results from the MedGem during this study, the MedGem was connected to the serial port of a laptop computer. During the test, a noseclip was used, and the subjects breathed through the MedGem mouthpiece for 10 minutes or until a steady breathing state was achieved. Internal components used sensor measurements of humidity, temperature, and barometric pressure to allow accurate determination of minute volume. A proprietary dual-channeled fluorescent quenching sensor measured oxygen concentration in the inspired and expired airflow. The primary principle of operation utilizes deactivation of ruthenium in the presence of oxygen. A ruthenium cell is excited by an internal light source and fluoresces. This reaction is repressed by the presence of oxygen. The magnitude of the repression is proportional
to the concentration of oxygen. The response time of the sensor is 50 ms and the oxygen concentration is sampled at 10 Hz. Ultrasonic sensing technology measures the volume of inspired and expired air. A transducer at both ends of the flow tube emits a sound pulse. The time it takes the signal to travel from the sending transducer to the receiving transducer is increased or decreased in proportion to the rate and direction of airflow. The sensors operate at a rate of 100 Hz. RMR is calculated from oxygen consumption, a fixed respiratory quotient (RQ) of 0.85, and grams of urinary nitrogen calculated from the average energy and protein intake of the United States population using a modified Weir equation:

\[
\text{Energy Expenditure} = (3.941 \times VO_2) + (0.85 \times 1.106 \times VO_2) - (2.17 \times \text{grams urinary nitrogen})
\]

\[VO_2\] is in L per day\(^{-1}\); grams of nitrogen = [(kcal per day\(^{-1}\) x 1.16)/4] / 6.25.

MedGem sensor specifications are as follows: pressure ±4 mm Hg with a resolution of 0.05 mmHg; temperature, ±1° C; humidity, ±4.2% rh, 0.01%; oxygen, ±0.4%-0.8% O\(_2\), 0.03% O\(_2\); volume, ±0.5%, 0.001 L/s.

**DeltaTrac**

Prior to each measurement the Deltatrac was calibrated for pressure against the local barometric pressure measured by a mercury barometer and the gas analyzers were calibrated against a known standard gas consisting of 96% oxygen and 4% carbon dioxide. The DeltaTrac collected expired gases in a canopy for 10 minutes, but used
only the last 8 minutes in calculation. The device consists of a 4-L mixing chamber, a paramagnetic oxygen analyzer, infrared CO\textsubscript{2} analyzer, microprocessor, and CRT display. The expired gases travel from the canopy to the mixing chamber where the gases are measured. The gases are then diluted with room air by the flow generator making the total flow (Q) through the system is equal to the flow generator’s output. V\textsubscript{CO2}, V\textsubscript{O2}, and RQ are then calculated using the following equations:

\[
V_{CO2} = Q(FCO_2)
\]

\[
V_{O2} = \left(\frac{Q}{1-F_{IO2}}\right) \left[F_{O2} - (F_{IO2}) (FCO_2)\right]
\]

\[
RQ = \frac{VCO_2}{VO_2}
\]

FCO\textsubscript{2} is fractional concentration of carbon dioxide
FO\textsubscript{2} is fractional concentration of oxygen
F\textsubscript{IO2} is fractional inspired concentration of oxygen

**Results**

Fifty subjects, consisting of 12 men and 38 women, completed the study. Subject characteristics are shown in Table 1, with data summarized for age, height, and weight.

Table 1: Characteristics for all subjects (N=50)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean ± SD\textsuperscript{a}</th>
<th>Range</th>
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</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>35.8 ± 13.2</td>
<td>20-69</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>169.2 ± 9.4</td>
<td>152-188</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>72.9 ± 17.0</td>
<td>52.3-123.6</td>
</tr>
</tbody>
</table>

SD\textsuperscript{a} = standard deviation
Oxygen consumption and RMR data are summarized in Figures 1 and 2.

**Figure 1**: Comparison of oxygen consumption (VO₂) values between the MedGem and DeltaTrac methods (N=50, all subjects combined)
Figure 2: Comparison of resting metabolic rate (RMR) values between the MedGem and DeltaTrac methods (N=50, all subjects combined)

Bland-Altman plots demonstrate the difference score between the two methods (DeltaTrac and MedGem) (Figure 3).
Mean oxygen consumption and RMR did not significantly differ between methods, with a mean difference of $0.58 \pm 15.33$ ml per min$^{-1}$ ($p = 0.790$) and $4.66 \pm 113.39$ kcal per day$^{-1}$ ($p = 0.773$) and an absolute difference of $12.3 \pm 8.99$ ml per min$^{-1}$ and $86.58 \pm 72.32$ kcal per day$^{-1}$, respectively. Correlation coefficients for oxygen consumption and RMR were 0.945 and 0.941, respectively.
Discussion

The purpose of this study was to simultaneously compare the VO$_2$ and RMR measurements of the DeltaTrac indirect calorimeter with the MedGem. The MedGem is the first portable, inexpensive, handheld device designed to make such measurements. No significant difference was found between devices. Our data suggests that the MedGem can accurately measure RMR and VO$_2$ in spontaneously breathing subjects who do not require supplemental oxygen. This study advances the research of Nieman et al, and Melanson et al, in that we used simultaneous measurements to compare the accuracy and precision of the MedGem and the DeltaTrac.$^{12,15}$

Confounding variables seen in other studies, such as changes in positioning or breathing between tests, that could potentially alter the measurements were reduced or eliminated by simultaneous testing. Even minimal activity, such as subjects holding the device to their mouth, could increase the subjects’ oxygen consumption. Any variation in the subjects’ breathing patterns between tests could also vary the test results. For example, if the subject was more relaxed during the testing of the MedGem device, the measurements taken by the MedGem would reflect a lower RMR and oxygen consumption. Nieman et al. compared the measurements from the MedGem with the measurements made by the Douglas bag technique.$^{12}$ Mean oxygen consumption and RMR were not significantly different between methods, with a mean difference of 0.9±19.0 mL per min and 7±134 kcal per day. Correlation coefficients for oxygen consumption ranged from 0.81-0.87 when comparing data from the MedGem to the Douglas bag method. Melanson et al. compared the measurements from the
MedGem with the measurements made by Sensormedics 2900 Ventilated Hood system, a standard metabolic cart. The results indicated strong agreement in RMR measured by the MedGem and the Sensormedics 2900 cart. The trial-to-trial intraclass reliability coefficients were above 0.90 for both the MedGem and Sensormedics 2900. Additionally, the RMR measured with the MedGem and the Sensormedics 2900 were highly correlated. The limitations of this study include scientific and mechanical differences between the two devices, subjects’ responses to the test, and the health status of the subject. Table 2 compares characteristics of the MedGem and the DeltaTrac.

Table 2: Characteristics of the MedGem and DeltaTrac

<table>
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<tr>
<th>Characteristic</th>
<th>MedGem</th>
<th>DeltaTrac</th>
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<tbody>
<tr>
<td>Expense</td>
<td>$2,500</td>
<td>$25,000+</td>
</tr>
<tr>
<td>Size</td>
<td>Hand-held</td>
<td>Cart-held</td>
</tr>
<tr>
<td>Weight</td>
<td>&lt;1#</td>
<td>20-30#</td>
</tr>
<tr>
<td>Population</td>
<td>spontaneously breathing</td>
<td>ventilated or non-ventilated</td>
</tr>
<tr>
<td>Measurements</td>
<td>VO₂, RMR</td>
<td>VO₂, VCO₂, RMR, RQ</td>
</tr>
<tr>
<td>Collection method</td>
<td>facemask or mouthpiece</td>
<td>canopy</td>
</tr>
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Each device uses different equations to calculate the RMR. The DeltaTrac uses both VO₂ and VCO₂, whereas the MedGem uses only VO₂. For this reason, the respiratory quotient (RQ) cannot be obtained using the MedGem. In cases of hyperventilation, VCO₂ maybe elevated and result in an increase in RMR calculated by the DeltaTrac. Because the MedGem does not consider VCO₂, this could account for differences in RMR between the devices. Second, the devices’ mechanical differences
limit the study. The DeltaTrac consistently measures the subjects’ breathing for 10 full minutes. The MedGem runs the test for 10 minutes or until a steady breathing state is achieved. In this study, 20 subjects reached a steady breathing state before 10 minutes of testing were completed. The remaining 30 subjects were tested with both devices for 10 full minutes. Third, the physical comfort of the subjects may also have limited the study. The use of a mouthpiece and noseclips may cause mild discomfort. Throughout the testing procedures, the researchers encouraged the subjects to communicate any discomfort. Testing with a mouthpiece and noseclips has been shown to increase oxygen consumption by 7.9% when compared to testing with a ventilated canopy.\textsuperscript{16} Lastly, this study only included healthy subjects. Persons with compromised health status may have a higher RMR and may not have the ability of maintain the 10-minute testing period needed for accurate measurement due to the use of the mouthpiece or noseclips.

**Conclusion**

These findings suggest that the MedGem provides an accurate and reliable measure of oxygen consumption and RMR measurements for spontaneously breathing subjects respiring room air. A statistically significant difference did not exist between the measurements from the two devices.

Further research is needed to compare the RMR measurements of the MedGem and the Harris Benedict predictive equation. Other research is needed to test the effectiveness of the MedGem in determining the kcalorie needs of the morbidly obese. Clinicians continue to struggle to provide appropriate nutritional support to those
patients whose Body Mass Index > 30. The Harris Benedict equation considers weight in predicting a patient’s RMR, and as a result, an obese patient’s estimated needs may be easily overestimated. Other future research to consider is comparing the measurements from MedGem and a standard metabolic cart using persons with compromised health status.

Implications of the findings from this research for practitioners and researchers include the validation of a handheld device which is easy to operate and available at a relatively low cost. The results of this study indicate the MedGem device can be used to accurately measure RMR and oxygen consumption in capacities where a traditional metabolic cart would not be practical or cost-effective, including long term care facilities, low-capacity hospitals, athletic training centers, health clubs, and weight loss clinics. Dietetic professionals in these settings could use the MedGem as part of their nutritional assessment in an individualized nutrition counseling session.

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