A pocket-sized metabolic analyzer for assessment of resting energy expenditure

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1. Introduction

The balance between energy intake and energy expenditure is key to weight management and obesity prevention in adults. An accurate assessment and tracking of total energy expenditure (TEE) can guide individuals to achieve proper energy balance.1 To date, most end-consumer commercial devices monitor energy expenditure related to physical activity by using physical sensors, such as accelerometers and GPS-distance tracking.2,3 While important for long-term health outcomes, physical activities typically count for less than 15% of TEE.1 TEE also includes a small portion of energy expenditure related to food-induced thermogenesis, which is ~10%. In contrast to physical-activity energy expenditure and thermogenesis, resting energy expenditure (REE), represents the largest percentage (>75%) of TEE.1 REE is the energy expenditure required to maintain basic body functions in a resting state, which cannot be measured by the physical sensors mentioned above. Furthermore, the physical-activity sensors are inadequate for...
monitoring low-energy physical activities, such as office work.\textsuperscript{4,5} For these reasons, determining REE may be critically important for weight management programs.

In fact, the American Dietetic Association has strongly recommended the use of REE measures for adult weight management.\textsuperscript{6} Various equations have been developed to calculate REE, but the accuracy of the equations is questionable, particularly for overweight and obese populations,\textsuperscript{7} athletes, and patients undergoing weight loss.\textsuperscript{8–11} The most widely accepted method for measuring REE is indirect calorimetry, which determines REE based on oxygen consumption (\(\text{VO}_2\)) and carbon dioxide production (\(\text{VCO}_2\)) rates using the Weir equation.\textsuperscript{1,6} A simplified approach is to detect \(\text{VO}_2\) alone and estimate REE by assuming a fixed ratio of \(\text{VCO}_2/\text{VO}_2\) (0.85). The ratio between \(\text{VCO}_2/\text{VO}_2\) is defined as the respiratory quotient (RQ), which can vary over a wide range (e.g., 0.7–1.0). Therefore, it is desirable to perform indirect calorimetry by measuring both the \(\text{VO}_2\) consumption and \(\text{VCO}_2\) production rates.\textsuperscript{1}

Indirect calorimetry can be performed using several methods, which include room calorimeters, metabolic carts, and the Douglas bag method,\textsuperscript{1,12} but these methods are unsuitable for personal use at home. A handheld device and other small analyzers have been developed,\textsuperscript{13,14} but they determine REE based on the detection of consumed \(\text{VO}_2\) only, which is subject to the limitation discussed above.\textsuperscript{1}

To address these limitations, the purpose of the present study is to evaluate the accuracy of a new pocket-sized metabolic analyzer (Fig. 1), which uses an integrated sensor technology for simultaneous detection of \(\text{VO}_2\) and \(\text{VCO}_2\), and has the ability to determine both REE, as well as energy expenditure (EE) of low-level physical activity. The device, in combination with existing commercial physical-activity energy-expenditure trackers, creates the opportunity for a more accurate assessment of TEE in free-living conditions, and therefore, individual’s caloric needs.

### 2. Materials and methods

#### 2.1. Subjects

Seventeen adult subjects (10 males, 7 females) from Arizona State University (ASU) voluntarily participated in the study. The study included healthy individuals and women who were not pregnant or nursing. The number of subjects was chosen based on a power calculation\textsuperscript{15} estimated from typical mean and standard deviation values for REE.\textsuperscript{10} Assuming a typical mean value for REE of 1800 kCal/day, with a standard deviation of 200 kCal/day (10% error), a sample size of 16 subjects allows detection of a difference in REE values (e.g. 1800 and 1600 kCal/day) with a power of 0.80. In the present study, the 17 subjects contributed with a total of 31 online measurements of energy expenditure (described below). Physical characteristics of the subjects, including fat, lean body, and muscle mass, were assessed (Table 1). The physical characteristics represented a relatively broad range, from under weight to obese: body mass index (BMI) ranged from 15.7 to 36.9 kg/m\(^2\).\textsuperscript{16} The study followed a protocol approved by the Institutional Review Board of Arizona State University (IRB protocol #4012005855). All subjects provided written informed consent prior to participation. The study was carried out at ASU from January 2011 to July 2011. In addition, measurements related to off-line testing involved 17 subjects and were performed at ASU from July 2011 to July 2012.

#### 2.2. Study overview

The subjects of the study participated in the measurements as follows. Fifteen subjects participated in the REE measurement group, which refrained from structured physical activity for 24 h prior to the REE measurement, and fasted (with no beverages or caffeine) for 12 h before the REE test to avoid the diet-induced

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### Fig. 1. Metabolic analyzer device. The device simultaneously detects the consumed oxygen and produced carbon dioxide, and the exhalation rate, from which energy expenditure is determined. It is paired to a cell-phone, which records the metabolic parameters, and track the personal metabolic history of users. Sequence of use: 1- Use of the sensor integrated mouthpiece to collect breath sample. 2- The sensor integrated mouthpiece is assembled to the cell-phone to analyze the sensor signal. 3- The user interface in the cell phone displays the results.
thermic effect. The subjects were permitted to drink water before the test. On the other hand, sixteen subjects participated in the EE group, which fasted for at least 4 h, but had no restrictions on caffeine or beverage intake and structured physical activity. This group was assessed for Energy Expenditure (EE) during routine activities, which included office and bench work. The office work included paperwork and computer work, and the bench work included assembly of electronic components and lab bench work. The test was performed after 2 consecutive hours of work, and the subjects stopped their activities right before the assessments. Both REE and EE measurement groups were assessed using the metabolic analyzer and Douglas bag method (see details below). It is worth noting that from the total study group of 17 subjects, REE and EE measurements for two subjects and one subject, respectively, were excluded due to non-compliance with the preparatory conditions at the time of measurement. In addition, EE measurements were not corrected by caffeine intake.

In order to classify the physical activity level of the study group, the subjects reported frequency, duration, and type of physical activities from the Compendium of Physical Activities published by Ainsworth et al. In addition, the subjects completed the International Physical Activity Questionnaire (IPAQ- 7 day, self-administered format), which classifies the population as “Low,” “Moderate,” or “High” physical activity level. The subjects in this study were categorized as “Low” physical activity level.

2.3. Body composition and anthropometric measurements

Body weight, height, as well as waist and hip circumferences were measured before the assessment of VO2 and VCO2, following the procedure specified by the American College of Sports Medicine’s Guidelines for exercise testing and prescription. BMI was calculated as Weight/Height2 (kg/m2). Seven-site skinfold test was performed on all subjects using a Harpenden skinfold caliper to calculate body density, and Siri equation was applied to calculate fat percentage. The skinfold and circumference measurements were taken 3 times each and the mean value of the 3 measurements was determined. The data was recorded and met the technical measurement error allowed by the International Society for the Advancement of Kinesiometry. In addition, the muscle mass of each subject was estimated using Lee’s equation. It is worth noting that the skinfold method was preferred over the bioimpedance analysis method. This is because the body fat percentage values by bioimpedance showed a variability higher than 20% when measured consecutively in the same subject under the same conditions.

2.4. Metabolic analyzer device

The pocket-sized metabolic analyzer in this study is designed to be used with a smartphone and does not require professional calibration to operate. The metabolic analyzer consists of a mouthpiece built with a non-rebreathing Hans-Rudolph valve, and an integrated O2 and CO2 sensor. The integrated O2 and CO2 sensor is a patented technology developed at ASU, and has been thoroughly tested and validated for specificity, sensitivity, stability and lifetime against high humidity and variable temperature conditions of breath. A related application (app) is run on a smartphone to provide a user-friendly interface and real-time data display, storage, and transmission of the metabolic parameters. The smartphone offers signal processing capability to the device, and introduces a user interface that is familiar to most users. An Android-based smartphone (HTC Evo 4G) was used for the present study. After the app is launched, the user is prompted to log in with their user name and password. Each user creates an account, inputting personal information, such as date of birth, height, and current weight. Once the user is logged in, the app guides the user to perform the test, and displays the measured energy expenditure.

To obtain REE measurements, subjects were asked to sit quietly for at least 15 min before each measurement. In contrast, to measure EE related sedentary activities, the energy expenditure measurements were carried out during the sedentary activities. During the REE and EE measurements, the room temperature was maintained at 23 °C. Before the metabolic analyzer was used, each subject was instructed to breathe using a mouthpiece not connected to the device for 2 min, while wearing a nose clip. Next, the integrated O2 and CO2 sensor of the metabolic analyzer was connected to the exhalation port of the mouthpiece, and the sensor analyzed a 4 L volume of exhaled breath. The exhaled breath was collected in a 4-L bag attached to the outlet of the device (see validation of collected exhaled volume). The bag has an error of <2%, which was determined by use of a calibration syringe (Vacumet, Ventura, CA). The time duration for collecting 4 L exhaled breath was recorded, which was used for determining the exhalation flow rate, and associated VO2 and VCO2 (Fig. 1). The energy expenditures of the subjects in the REE and EE groups were calculated from VO2 and VCO2 using the Weir equation given by EE = [3.9(VO2) + 1.1(VCO2)] × 1.44 (1)

where EE is kCal/day, and VO2 and VCO2 are the consumed oxygen rate and produced carbon dioxide rate in mL/min. VO2 and VCO2 were determined by the exhalation rate (VE), and exhaled oxygen and carbon dioxide concentration from the integrated O2 and CO2 sensor, with VE corrected by ambient pressure and temperature, and water vapor pressure of water.

2.5. Validation of collected exhaled breath volume

The exhaled volume of 4 L collected under the conditions described above was validated by comparing the results with the exhaled volumes determined with the Douglas bag method. 4 L exhaled breath volume was collected between 0.5 – 1 min, and 40 L exhaled breath volume was collected between 5 and 10 min, respectively, for each of 11 subjects. From the volumes and time durations, as well as measured O2 and CO2 concentrations of the collected breath samples, VE and exhaled O2 and CO2 concentrations were determined. Differences of VE for both collection conditions were smaller or equal to 3.5%, with Diff. % defined as: [[(4 L collection- 40 L collection)/mean value of both collection methods]]. This procedure validated the exhaled breath volume condition, and suggested that a 4 L breath sample collected after a

<table>
<thead>
<tr>
<th>Physical characteristics of the study’s subjects (n = 17).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
</tr>
<tr>
<td>--------</td>
</tr>
<tr>
<td>Female</td>
</tr>
<tr>
<td>Male</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>
expenditure (REE) values were analyzed from paired samples. As a note, the linear regression analysis with null intercept was chosen for the correlation method, following the recommended statistical procedure to assess worst-case correlation between variables that are not expected to render null meaningful values. In addition, when null intercept correlation analysis is applied to two methods (tested method vs. reference method), the correlation slope is directly indicative of the accuracy of the tested method vs. the reference method.28

3. Results

The analytical accuracy of VO$_2$, VCO$_2$ and energy expenditure measurements from the metabolic analyzer device was compared with that of the Douglas bag method for both study groups, REE ($n=15$ measurements) and EE ($n=16$ measurements), covering a range of energy expenditure values from ~1000 to 3500 kCal/day. Linear regression analysis, paired t-tests, and Bland–Altman plots were performed to achieve this task as follows:

3.1. Linear regression analysis

Scatter plots of VO$_2$, VCO$_2$ and energy expenditure measured by the metabolic analyzer device and the Douglas bag method are presented in Fig. 2a–c. The results from the linear regression analysis show the following slope, LRS$_0$, and R-squared coefficient, $r^2$ with $p=0$: LRS$_0$ $\pm$ SD = 1.00 $\pm$ 0.01, $r^2 = 0.9933$ for VO$_2$; LRS$_0$ $\pm$ SD = 1.00 $\pm$ 0.01, $r^2 = 0.9929$ for VCO$_2$; and LRS$_0$ (SD) = 1.00 $\pm$ 0.01, $r^2 = 0.9942$ for energy expenditure, for both resting and sedentary activity parameters. Table 2 shows more detailed linear regression analysis of VO$_2$, VCO$_2$ and energy expenditure discriminated by group (resting and sedentary activity). The differences for VO$_2$, VCO$_2$, REE and EE determined by the two methods are 1.4 mL/min, -0.8 mL/min, -59 kCal/day, and 40 kCal/day, respectively, which are only 0.6, 0.4, 3.2 and 2.5% of percentage difference (Diff. %), respectively, with Diff. % defined as: ([Metabolic analyzer device parameter − Douglas bag method parameter]/[mean value of both methods]). In addition, no significant differences were found between the two methods for any of the measurements.

3.2. Paired t-tests

To analyze the accuracy of the new pocket-sized metabolic analyzer, the values of VO$_2$, VCO$_2$, REE, and EE measured with the device were compared with these by the Douglas bag method, and the correlation between the two methods was analyzed using linear regression method. In addition, the values of VO$_2$, VCO$_2$, REE, and EE from the two methods were analyzed from paired t-tests to determine the statistical difference of the readings by the metabolic analyzer and the Douglas bag method. Furthermore, resting energy expenditure (REE) values were analyzed via Bland–Altman plots. Linear correlation analysis between REE group measurements and the physical characteristics of the subjects (body weight, BMI, lean body mass and muscle mass) was performed to determine how REE values from the metabolic analyzer fit with existing trends between REE and the physical characteristics of the subjects.

As a note, the linear regression analysis with null intercept was chosen for the correlation method, following the recommended statistical procedure to assess worst-case correlation between variables that are not expected to render null meaningful values. In addition, when null intercept correlation analysis is applied to two methods (tested method vs. reference method), the correlation slope is directly indicative of the accuracy of the tested method vs. the reference method.28

2-min breathing period can provide REE results that are indistinguishable from those obtained in larger-volume (e.g., 40 L) breath samples.

2.6. Modified Douglas bag method

A modified Douglas bag method, simply called the Douglas bag method here, was carried out using breath samples collected in the 4-L bags during the energy expenditure test with the metabolic analyzer. Note that the adsorption of O$_2$ and CO$_2$ by the sensors in the analyzer was found to be <0.01%, which is negligible compared to the relatively high O$_2$ and CO$_2$ concentrations in exhaled breath. A galvanic fuel cell O$_2$ analyzer (Vascular Technology, Nashua, NH) and an infrared CO$_2$ analyzer (GE, Goleta, CA) were used to measure the O$_2$ and CO$_2$ concentrations, respectively, from which the flow rate of the consumed VO$_2$ and produced VCO$_2$ rates were determined. Both sensors were adapted for breath measurements using Nafion tubing (Permapure, LLC), and mini pump (Parker Hannifin Corp). The Na$_2$O$_2$/CO$_2$ sensors were calibrated using dilutions prepared from pure air (Praxair) and humidity in the Na$_2$O$_2$ converter, which (according to the manufacturer) guarantees 10% humidity, which (according to the manufacturer) guarantees 10% humidity in the Na$_2$O$_2$ tubing outlet. The commercial analyzers were calibrated using dilutions prepared from pure air (Praxair) and medical-grade standard calibration gas containing 16.6% O$_2$ and 4.0% CO$_2$ (Vacumetrics Inc., Ventura, CA). Based on the measured VO$_2$ and VCO$_2$, energy expenditure (REE or EE) was calculated using the Weir equation.26 Finally, $V_t$ was corrected by ambient pressure and temperature, and water vapor pressure of water.

2.7. Statistical analysis

To analyze the accuracy of the new pocket-sized metabolic analyzer, the values of VO$_2$, VCO$_2$, REE, and EE measured with the device were compared with these by the Douglas bag method, and the correlation between the two methods was analyzed using linear regression method. In addition, the values of VO$_2$, VCO$_2$, REE, and EE from the two methods were analyzed from paired t-tests to determine the statistical difference of the readings by the metabolic analyzer and the Douglas bag method. Furthermore, resting energy expenditure (REE) values were analyzed via Bland–Altman plots. Linear correlation analysis between REE group measurements and the physical characteristics of the subjects (body weight, BMI, lean body mass and muscle mass) was performed to determine how REE values from the metabolic analyzer fit with existing trends between REE and the physical characteristics of the subjects.
difference between the two methods’ values was found for a significance level $\alpha = 0.05$ for VO$_2$, VCO$_2$, REE and EE.

### 3.3. Bland–Altman plot

Figure 3 shows a Bland–Altman plot built for REE results to closely evaluate the differences between the metabolic analyzer device and the Douglas bag method for diagnosis of resting energy expenditure. Applying a linear fit onto the plot data results in a null slope and a random averaged difference (metabolic analyzer device – Douglas bag method) $\leq$10%.

In order to further evaluate the capability of the metabolic analyzer to differentiate between different metabolic rates, an additional regression analysis was performed with the REE values obtained from the metabolic analyzer and the body composition of the subjects. Fig. 4(a–d) shows a relationship of the REE measured by the metabolic analyzer to weight, BMI, lean body mass, and muscle mass assessed via anthropometric measurements. R-squared coefficients ($r^2$) between REE values and the physical characteristics of the subject larger than 0.96 with $p = 10^{-13} - 10^{-11}$ were found. R-squared coefficient was especially high ($r^2 \approx 0.98$) for muscle mass. This finding is consistent with previous results reported in literature.²

In addition, the accuracy of the metabolic analyzer was tested for off-line measurements, which was implemented via collection of the breath sample in a sample bag, and an external pump-assisted delivery to the analyzer. The results of the off-line method showed linear regression plots with LRS$_0$ ± SD = 1.00 ± 0.02, and $r^2 = 0.977$ ($p = 0$) for values obtained by metabolic analyzer vs. Douglas bag method (Supplementary Data). In addition, Bland–Altman plots constructed similarly to on-line test analysis showed 100% of the results within the predefined acceptance criteria of ±2SD (Supplementary Data). In conclusion, the off-line testing of the metabolic analyzer device is also able to provide as accurate and reliable REE measurement as the on-line testing.

### 4. Discussion

This study compared a new metabolic analyzer method to the Douglas bag method, a reference method for measurements of human metabolism, in order to provide an evaluation of relative accuracy with a well-established method. The linear correlation analysis from measurements performed with the metabolic analyzer resulted in small differences.

### Table 2

Linear regression analysis results by activity level.

<table>
<thead>
<tr>
<th>Activity</th>
<th>LRS$_0$</th>
<th>SD</th>
<th>$r^2$</th>
<th>$t$</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>VO$_2$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resting</td>
<td>1.04</td>
<td>0.02</td>
<td>0.9964</td>
<td>64.0</td>
<td>0</td>
</tr>
<tr>
<td>Sedentary activity</td>
<td>0.96</td>
<td>0.02</td>
<td>0.9928</td>
<td>47.0</td>
<td>0</td>
</tr>
<tr>
<td>VCO$_2$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resting</td>
<td>1.01</td>
<td>0.02</td>
<td>0.9934</td>
<td>47.4</td>
<td>0</td>
</tr>
<tr>
<td>Sedentary activity</td>
<td>0.98</td>
<td>0.02</td>
<td>0.9922</td>
<td>45.2</td>
<td>0</td>
</tr>
<tr>
<td>Energy expenditure</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resting</td>
<td>1.03</td>
<td>0.01</td>
<td>0.9967</td>
<td>66.9</td>
<td>0</td>
</tr>
<tr>
<td>Sedentary activity</td>
<td>0.97</td>
<td>0.02</td>
<td>0.9935</td>
<td>49.5</td>
<td>0</td>
</tr>
</tbody>
</table>

$^a n = 15.$

$^b n = 16.$

### Table 3

Paired t-test comparison of metabolic analyzer device and Douglas bag method.

<table>
<thead>
<tr>
<th>VO$_2$ (ml/min)$^a$</th>
<th>Mean</th>
<th>SD</th>
<th>SEM</th>
<th>Mean difference</th>
<th>SD</th>
<th>$p$</th>
<th>$t$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Device</td>
<td>247.6</td>
<td>85.4</td>
<td>15.3</td>
<td>3.8</td>
<td>0.70</td>
<td>0.39</td>
<td></td>
</tr>
<tr>
<td>Douglas bag</td>
<td>246.2</td>
<td>85.2</td>
<td>15.3</td>
<td>1.4</td>
<td>0.84</td>
<td>0.21</td>
<td></td>
</tr>
<tr>
<td>VCO$_2$ (ml/min)$^a$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Device</td>
<td>217.3</td>
<td>82.3</td>
<td>14.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Douglas bag</td>
<td>218.1</td>
<td>78.2</td>
<td>14.0</td>
<td>−0.8</td>
<td>3.5</td>
<td>0.001</td>
<td>1.88</td>
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<tr>
<td>REE (kCal/day)$^b$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Device</td>
<td>1897</td>
<td>627</td>
<td>162</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Douglas bag</td>
<td>1838</td>
<td>577</td>
<td>149</td>
<td>−59</td>
<td>30.9</td>
<td>0.081</td>
<td>1.88</td>
</tr>
<tr>
<td>EE (kCal/day)$^c$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Device</td>
<td>1584</td>
<td>571</td>
<td>143</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Douglas bag</td>
<td>1624</td>
<td>622</td>
<td>155</td>
<td>−40</td>
<td>35</td>
<td>0.271</td>
<td>1.144</td>
</tr>
</tbody>
</table>

$^a n = 31.$

$^b n = 15.$

$^c n = 16.$

Abreviations: LRS$_0$: linear regression slope with null intercept; SD: standard deviation; $r^2$: R-squared coefficient; SEM: standard error of the mean; Mean difference: (Device mean value − Douglas bag mean value); $p$: $p$ value from the paired $t$-test; $t$: $t$ value from paired $t$-test; VO$_2$: oxygen consumption rate, VCO$_2$: carbon dioxide consumption rate, REE: Resting Energy Expenditure, EE: Energy Expenditure during sedentary activities.
underscoring the importance of measuring (not calculating) REE for accurate analysis of energy expenditure.

Finally, REE values assessed from the metabolic analyzer correlate well ($r^2 > 0.96$, $p = 10^{-13}$) with the physical parameters, such as weight, BMI, lean body mass and muscle mass of the subjects, indicating the capability of the device for discriminating different resting metabolic rates with physical parameters.

Using the Douglas bag method as a reference method requires several measurements from separate instruments (e.g. oxygen and carbon dioxide, separately). Other metabolic instruments based on oxygen and carbon dioxide detection have been developed (e.g. Oxycon Mobile by CareFusion, Yorba Linda, CA) to facilitate the measurement of energy expenditure. The metabolic analyzer presented here has demonstrated analytical performance comparable to these instruments (not shown). The traditional commercial instruments are relatively high in price and require calibration and operation by professionals. Along this line, several features make the metabolic analyzer advantageous for more widespread use: 1) calibration-free, 2) easy to operate, 2) high portability 3) seamless pairing with smartphones. All subjects of the study were able to independently use the metabolic analyzer to achieve accurate results without supervision of professionals.

The metabolic analyzer uses pre-calibrated sensor cartridges fabricated with reproducibility higher than 97% (Supplementary Data) and the sensor cartridges have been demonstrated to have a lifetime of a year (Supplementary Data). The core technology of the metabolic analyzer is based on the creation of sensitive colorimetric sensing materials, optimization of optoelectronic detection, and design of sample collection and delivery system. These advances made it possible to build the metabolic analyzer device that is small (pocket-sized) and lightweight (2.8 oz), and robust.

5. Conclusion

A systematic study has been carried out to test and evaluate a pocket-sized metabolic analyzer. The study shows that the metabolic analyzer device provides accurate measurements of VO2 and VCO2, which enables accurate determination of energy expenditure. This capability is especially relevant for overweight or obese populations under weight loss programs. Compared to the traditional technology, the pocket-sized metabolic analyzer allows for accurate energy expenditure assessment at home, which is suitable for weight management.

Conflict of interest statement

Authors have no conflict of interest.

Acknowledgments

This study was supported by Arizona State University. DZ optimized sensor cartridge development and calibration, and
performed analytical validation of on-line measurement of the metabolic analyzer device against the gold standard method, LZ implemented off-line measurement of the metabolic analyzer device, and validation against gold standard method, MT performed anthropometric characterization of subjects, clinical validation of the metabolic analyzer device, and assisted software development, RK developed software and cell phone application of the new device, DM developed the hardware for sensor cartridge holder and RK developed software and cell phone application of the new device, and assisted software development, RJ supervised physics, opto-electronics of the new device, EF supervised analytical, statistical and sensor cartridges, FT ensured the quality of optoelectronic components of the new device, DB, KT and XX developed new methods for reproducible mass production of optical and vice, and assisted software development, and NJT supervised physics, opto-electronics, and software aspects of the project.

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.clnu.2013.06.001.

References