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Techniques, Materials, Devices

The Use of a Handheld Calorimetry Unit to Estimate Energy Expenditure During Different Physiological Conditions

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ABSTRACT. *Background:* Accurately determining rates of energy expenditure (EE) under free-living conditions is important in understanding the mechanisms involved in the development and prevention of obesity. Metabolic carts are not portable enough for most free-living situations. The purpose of this study was to compare a portable, handheld indirect calorimetry device (HealtheTech Incorporated, Golden, CO) to a metabolic cart (Physio-Dyne Instrument Corporation, Quogue, NY) during 3 different physiologic states. *Methods:* EE was measured by both the handheld calorimeter (5–10 minutes) and the metabolic cart (15–20 minutes) in 20 healthy subjects (18–35 years of age). Measurements were made during 3 physiologic states: (1) postabsorptive rest (REE), (2) postprandial rest (fed energy expenditure, FEE), and (3) while walking in place (activity energy expenditure, AEE). *Results:* There were no significant differences between the means of the cart *vs* the handheld device for REE (mean ± SE; kcal/d; 1552 ± 64 *vs* 1551 ± 63), FEE (1875 ± 99 *vs* 1825 ± 86), and AEE (3333 ± 218 *vs* 3489 ± 152). The range over which the techniques were tested was 1300–5000 kcal/d. The agreement between the 2 methods was excellent for REE (0.80, $p < .0001$), FEE (0.89, $p < .0001$), and AEE (0.75, $p < .0002$). *Conclusions:* Compared with the metabolic cart, the handheld device provided similar estimates of energy expenditure during resting, postprandial, and physically active states. This suggests that portable indirect calorimetry devices can provide reliable and valuable information in free-living research situations for which maximal energy expenditure is <5000 kcal/d. (*Journal of Parenteral and Enteral Nutrition* **30:**246–250, 2006)

Accurately determining rates of energy expenditure under free-living conditions is important to our understanding of several disease states, as well as our understanding of the mechanisms involved in the development and prevention of obesity. Traditionally, energy expenditure has been estimated using algebraic equations, which include variables such as weight, height, age, and gender with factors included for the level of stress and physical activity. However, the accuracy of these formulas has been questioned, and, over time, different methods of measuring energy expenditure have evolved.[1,2] The most common technique used to estimate energy expenditure is indirect calorimetry.[1,3–5] Respiration chambers and, more commonly, metabolic carts are devices that use indirect calorimetry to measure energy expenditure.

Metabolic carts have been shown to provide an accurate estimate of energy expenditure.[6] However, these carts are large, relatively cumbersome to use under free-living conditions, and not particularly portable.[7–9] Therefore, they are not feasible for use in free-living situations. Newly developed handheld indirect calorimeters may have potential for use in a wider range of settings because they are small, portable, and self-calibrating.

A few studies have examined the accuracy of a handheld indirect calorimeter (MedGem Indirect Calorimeter; HealtheTech, Inc, Golden, CO) by comparing it to a metabolic cart.[5,9–12] However, these studies only tested the handheld device during conditions of rest. The present study was designed to compare energy expenditure measured by a handheld device to energy expenditure measured by a metabolic cart (Physio-Dyne Instrument Corporation, Quogue, NY). The goal was to determine how closely the handheld device compared with the metabolic cart under 3 different physiologic conditions: postabsorptive rest, postprandial rest, and during modest physical activity.

MATERIALS AND METHODS

Subjects

Healthy, free-living subjects 18 years of age and older were recruited on the Iowa State University campus. Twenty subjects, including 6 men and 14 women, participated in the study. The study protocol, which was approved by the institutional review board of Iowa State University, was explained to each subject before they signed an informed consent document.

Handheld Indirect Calorimeter

An indirect calorimeter that can be held in the palm of the hand was used to measure energy expenditure.

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This calorimeter monitors inspired and expired air flow, oxygen levels, and environmental conditions to measure oxygen consumption.[13] The unit has a computer interface that allows the minute-by-minute data to be downloaded for analysis. A nose clip was used to ensure that all inspired and expired gases travel through the mouthpiece and flow tube. The calorimeter measured oxygen uptake (VO_2) in mL per minute. Using an assumed respiratory quotient (RQ) of 0.85, 24-hour energy expenditure was calculated using a modified Weir equation.[14] An LCD screen displayed the energy expenditure in kcal/d and VO_2 in L/d after completion of the measurement. The calorimeter is designed for estimating resting energy expenditure (REE); however, the documentation of the manufacturer notes that if a subject has been active or stressed, has eaten, or has exercised, the rate of oxygen consumption will be accurate for that condition. The handheld device has an upper limit of 721 mL/minute for VO_2, and, when exceeded, no data are collected and an error message is generated.

Before each measurement of energy expenditure, the handheld device performed a 30-second self-calibration.[13] All subjects were instructed on proper placement and positioning of the handheld indirect calorimeter per the instructions of the manufacturer, and subjects held the device during each tested physiologic state. After calibration, each subject breathed into the device through a mouthpiece while wearing a nose clip. The first 2 minutes of the measurement were not included in the calculation of energy expenditure. After the first 2 minutes, the device continued to collect data until a steady state was reached or until at least 8 minutes of additional data were collected. The average of the data collected was calculated to determine energy expenditure. The duration of the test ranged from a minimum of 5 minutes to a maximum of 10 minutes, with the average collection time being 8.5 minutes.

Metabolic Cart

In addition to the handheld device, a metabolic cart was used to measure energy expenditure. The metabolic cart is interfaced with 3 instruments: a system to continuously sample the airflow from the subject, a meter to record the volume of air breathed, and oxygen and carbon dioxide analyzers to measure the composition of the expired gas mixture.[15] The volume/airflow is measured by a pneumotach and mass flow transducer, O_2 is measured by a rapid paramagnetic analyzer, and carbon dioxide (CO_2) by a rapid infrared analyzer. VO_2, VCO_2, and RQ were provided on a minute-by-minute basis on a computer screen while each subject completed the measurement. The 24-hour energy expenditure was calculated from VO_2, VCO_2, and RQ using the Weir[14] equation. This device is designed to measure energy expenditure during resting, fed, and active conditions.

Before each measurement of energy expenditure, the metabolic cart was manually calibrated. The calibration procedure included measurement of the ambient temperature, humidity, and barometric pressure; calibration against a standard mixture of gas; and calibration of volume measurements using a 1-L syringe. After calibration, each subject was instructed to breathe into a mask that covered both their mouth and nose. This mask ensured that all inspired and expired gases were collected. Measurements of VO_2 and VCO_2 *via* the metabolic cart continued for 15 or 20 minutes. The first 5 minutes of each measurement were not included in the calculation of energy expenditure.

Energy Expenditure Protocols

After an overnight fast of at least 8 hours, the subjects reported to the Human Metabolic Unit (HMU) of the Center for Designing Foods to Improve Nutrition at Iowa State University between 6 and 8 AM. Weight and height were measured and age was verified for each subject. From this information, basal energy expenditure was calculated according to the Harris-Benedict and Mifflin–St. Jeor equations.[16,17] The subjects were then required to rest quietly while sitting comfortably for 20 minutes before the measurement of REE. The order in which the subjects were tested by the handheld device or the metabolic cart was random according to subject number. While the subjects continued to sit quietly, REE was measured for 20 minutes with the metabolic cart and for a maximum of 10 minutes with the handheld device. The maximum amount of time allowed to pass between any of the measurements was the 30 seconds needed to calibrate the handheld device. After the REE measurements, the subjects were allowed to leave the HMU but were instructed to return within 30 minutes after eating either breakfast or lunch.

After either breakfast or lunch, the subjects returned to the HMU and rested quietly, while sitting, for 20 minutes. After the rest period, fed energy expenditure (FEE) was measured using both indirect calorimetry devices. The devices were used in the same order and for the same duration as with the REE measurements. Therefore, FEE was determined approximately 60 minutes after their meal. The timing of the meal and the calories consumed were not recorded, because the primary comparison of interest was between the 2 indirect calorimetry techniques within the same subject. In fact, it was hoped that there would be differences between the meals consumed by the subjects to provide a broader range of FEE measurements.

Immediately after the FEE measurements, subjects walked in place at a comfortable pace (using a set metronome cadence) for a 5-minute warm-up period before the measurement of activity energy expenditure (AEE). While continuing to walk in place at the same pace, the subjects had their energy expenditure measured for 15 minutes with the metabolic cart and for a maximum of 10 minutes with the handheld device. The devices were used in the same order as with REE and FEE. Although the handheld indirect calorimetry device is not intended for estimating energy expenditure in active physiologic states, the investigators were interested in determining the accuracy of the device at higher rates of energy expenditure.

Statistical Analysis

Descriptive statistics, Pearson correlation coefficients, and Bland-Altman analyses were created using Microsoft Excel (version 11.0; Microsoft Corporation, Redmond, WA). The data are reported as means ± SE in kcal/d. Pearson correlation coefficients were used to determine the presence of a relationship between energy expenditure values measured by the handheld device and the metabolic cart. Bland-Altman analyses compared the mean of the 2 measurements *vs* the difference of the 2 measurements in each physiologic state for each subject.[18] This analysis allowed for the determination of whether variation between the 2 methods was related to increases or decreases in energy expenditure. In addition, the general linear models procedure of SAS 9.1 for Windows (SAS Institute, Inc, Cary, NC) was used to analyze differences between methods of determining energy expenditure using analysis of variance (ANOVA).

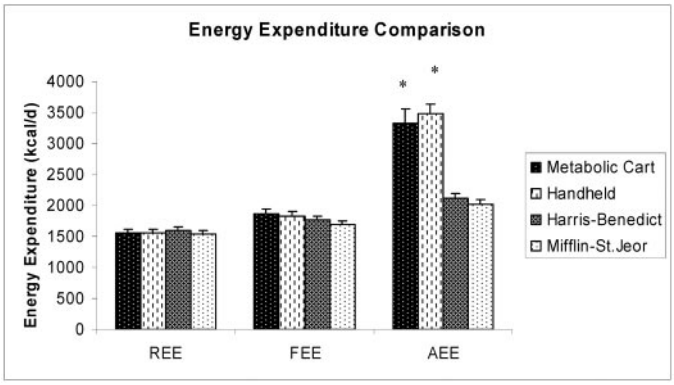

FIGURE 1. Bar graphs representing the mean energy expenditure in kcal/d in 3 physiologic states (REE, FEE, and AEE) according to the metabolic cart, handheld calorimeter, Harris-Benedict equation, and Mifflin–St. Jeor equation. * Denotes significant differences ($p < .0001$) between methods. REE, resting energy expenditure; FEE, fed energy expenditure; AEE, activity energy expenditure.

RESULTS

Subjects were white, 22.6 ± 3.6 years of age, weighed 68.9 ± 3.3 kg, and had an average body mass index of 23.5 ± 0.9 kg/m^2. Of the 20 subjects who participated in the study, 19 successfully completed the measurements in all 3 physiologic states. Only 1 subject, during FEE and AEE, had rates of VO_2 above the upper limit of 721 mL/min,[13] resulting in an error message on the handheld device. This particular subject had a body mass of 109.1 kg and an REE of 2320 kcal/d, as measured by the handheld indirect calorimeter.

The mean REE values for the 2 techniques were not statistically different from each other ($p > .05$). The handheld device estimated REE at 1551 ± 63 kcal/d compared with 1552 ± 64 kcal/d for the metabolic cart. The mean basal metabolic rate estimated by the Harris-Benedict equation was about 3% greater (1604 ± 58 kcal/d), and by the Mifflin–St. Jeor equation, about 1% less (1534 ± 54 kcal/d) than the REE measurements (Figure 1).

FEE was estimated as 1825 ± 86 kcal/d with the handheld device compared with 1875 ± 99 kcal/d for the metabolic cart. The mean FEE estimated by the Harris-Benedict equation was 3%–6% less (1764 ± 64 kcal/d) and by the Mifflin–St. Jeor equation about 8%–11% less (1688 ± 59 kcal/d). For each equation, a factor of 10% for thermic effect of food (TEF) was used.

Finally, AEE was 3489 ± 152 kcal/d with the handheld device *vs* 3333 ± 218 kcal/d for the metabolic cart. The mean AEE estimated by the Harris-Benedict equation was 36%–39% less (2117 ± 77 kcal/d) and by the Mifflin–St. Jeor equation about 39%–42% less (2026 ± 71 kcal/d). For each equation, a factor of 20% for physical activity was used.

The respiratory quotients measured by the metabolic cart were 0.83 ± 0.01, 0.87 ± 0.01, and 0.88 ± 0.01 for REE, FEE, and AEE, respectively. The handheld device assumed a respiratory quotient of 0.85 for each condition.

Overall, there was significant positive agreement between energy expenditure measurements using the 2 different devices (Figure 2; $r = 0.92$; $p < .0001$) when all of the paired values were considered together. For the individual periods measured, Pearson correlation analysis revealed positive relationships when the handheld device was compared with the metabolic cart for REE ($r = 0.80$; $p < .0001$), FEE ($r = 0.89$; $p < .0001$), and AEE ($r = 0.75$; $p < .0002$).

Using Bland-Altman analysis with the entire data pool (Figure 3), the average difference between the 2 techniques was very close to zero, and there was not a significant positive or negative slope for the relationship between the means and differences between the 2 techniques ($r = 0.03$). Upon visual examination, there appeared to be more variation as the mean energy expenditure increased, so further analysis was used to examine this variation by collapsing the data into 1000 kcal/d intervals. The average differences for these intervals (1000–2000, 2001–3000, 3001–4000, and 4001–5000 kcal/d) were 4, −140, −158, and 307 kcal/d, respectively. The standard errors for these values increased along with the energy expenditure of these groups (SE = 29, 121, 199, and 397, respectively),

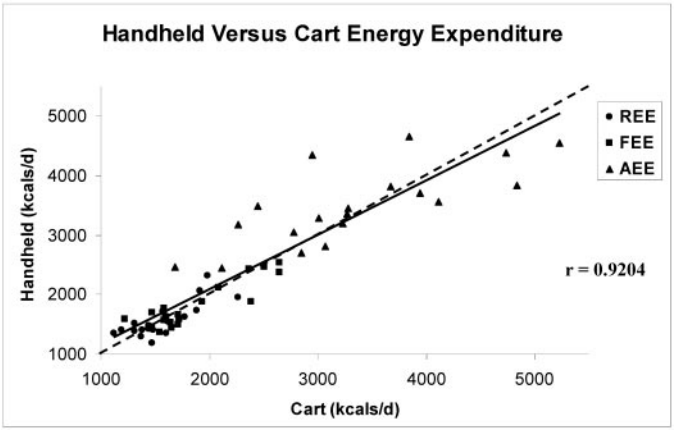

FIGURE 2. Relationships between energy expenditures using a metabolic cart and a handheld calorimeter during periods of REE, FEE, and AEE. The solid line represents the best fit, whereas the dotted line represents the identity line. REE, resting energy expenditure; FEE, fed energy expenditure; AEE, activity energy expenditure.

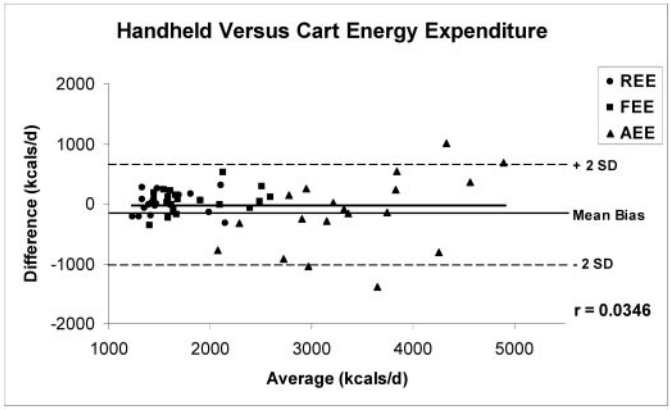

FIGURE 3. Bland-Altman plot comparing differences between and averages of the handheld device and the metabolic cart during REE, FEE, and AEE. The solid, dotted, and short lines represent the mean difference, 2 SD from the mean, and the linear data, respectively. REE, resting energy expenditure; FEE, fed energy expenditure; AEE, activity energy expenditure.

suggesting more variability at higher rates of energy expenditure. Further evidence of this pattern was obtained through analysis of the individual REE, FEE, and AEE periods. Although there was no significant slope or change in variation with changes in energy expenditure for REE ($r = 0.03$; $p < .91$) and FEE ($r = 0.29$; $p < .22$), there was moderately significant bias with AEE ($r = 0.49$; $p < .03$). The handheld device tended to underestimate energy expenditure at lower AEE and overestimate energy expenditure at higher AEE.

DISCUSSION

The growing epidemic of overweight, obesity, and related disease states requires accurate determination of energy expenditure under free-living conditions to explore etiologic mechanisms. Metabolic carts used to measure energy expenditure by indirect calorimetry are large and not particularly portable for use in free-living situations.[7–9] Recently developed handheld devices may have potential for use under a greater variety of conditions. However, these potential methods need to be examined for validity and reliability under these conditions using traditional indirect calorimetry.[1,2] In the present study, the handheld device and metabolic cart produced very similar estimates of energy expenditure during 3 different metabolic conditions. Furthermore, these significant positive relationships were demonstrated over a relatively wide range (1200–5000 kcal/d) of energy expenditure rates.

Bland-Altman plots showed no significant differences between lower and higher measurements of energy expenditure during the conditions of resting while fasting or fed (1300–2600 kcal/d). In order to determine the upper limits of the device, light activity in the form of walking in place was used. In this state, Bland-Altman plots showed that when rates of energy expenditure were greater (2000–5000 kcal/d), there appeared to be a slight bias such that the handheld device underestimated energy expenditure at lower levels and overestimated energy expenditure at higher levels.

FEE observed for both devices was higher than the typical TEF, which is estimated at 10%. This was likely related to the physical activity the subjects engaged in after leaving the HMU and returning after eating breakfast or lunch. Additionally, the AEE was higher than expected on both devices, related to the modest amount of physical activity performed. Physical activity factors used in prediction equations generally encompass a 24-hour period of time, where activities of daily living such as sleeping and sitting are factored in. This AEE does not include normal daily activity and is calculated as if the subject performed the same level of physical activity for 24 hours.

One of the limitations of the handheld device appears to be that it only directly measures oxygen consumption and the rate of air flow; therefore, it assumes that the RQ of the subject is 0.85. This assumption may be true for some but not all people. RQ as measured by the metabolic cart was actually 0.83 ± 0.01, 0.87 ± 0.01, and 0.88 ± 0.01 for REE, FEE, and AEE, respectively. However, when calculations of energy expenditure with the handheld device were made using these measured RQ values in place of the assumed 0.85 RQ value, the resultant changes in energy expenditure were relatively small (0.4%, 0.1%, and 1.3% different for REE, FEE, and AEE, respectively).[13] Nieman et al[19] also found that measured RQ only introduced 1.2% error (19 kcal/d) in REE. This is in contrast to Reeves and colleagues,[5] who found that the average measured RQ was lower than the assumed value of 0.85 by 17.6% in patients with cancer and by 15.3% in healthy subjects. This variation in RQ was calculated to provide an overall difference in energy expenditure of approximately 6.3% in cancer patients and 3.0% in healthy individuals.

Another limitation to this study was the short duration of the measurements, which may raise concerns about steady state. The measurements taken by the handheld device had a maximum duration of 10 minutes. The measurements taken by the metabolic cart lasted 20 minutes (REE and FEE) or 15 minutes (AEE). However, we noted that a plateau was reached under each of the conditions created, suggestive of steady state. Regardless of concerns over steady state, the agreement of the 2 methods was outstanding, even with the length of measurements used.

In addition, subjects may have had some difficulty holding the handheld device while walking in place. This may be related to the increased bias seen during the measurement of AEE. Finally, the subject population is quite homogeneous, which makes extrapolation of the results to other populations more difficult. Subjects of various ages who may be under- or overnourished, under- or overweight, or have illness could lead to different results.

Although our study suggests good agreement between the handheld device and the metabolic cart, recent research has shown mixed results regarding the accuracy of the handheld indirect calorimeter. Similar to the mean REE differences in our study (1 kcal/d), St. Onge et al[9] and Stewart et al[10] also found very

small mean differences in REE measurements (3.2 and 4.7 kcal/d, respectively). The first study[9] measured REE using the traditional device followed by the handheld indirect calorimeter. The second study[10] used both devices at the same time to measure REE and found very good agreement ($r = 0.94$). In contrast, Alam and colleagues[11] concluded that REE measurements obtained by the handheld device were consistently higher than the measurements obtained by the traditional indirect calorimeter in Bangladeshi women. On the other hand, Compher et al[12] compared 2 measurements made by the handheld device to 1 measurement made by the traditional device in stable patients using home nutrition support. The researchers found the handheld device to be very repeatable (mean difference between 2 measurements of 6.8 kcal/d), yet the handheld device was consistently lower (162 kcal/d) than the metabolic cart. The reasons for these reported discrepancies are not readily apparent but may be specific to each experimental milieu, suggesting the importance of validation under specific potential conditions of use.

In conclusion, the findings of the present study demonstrated strong agreement between a handheld indirect calorimetry device and a metabolic cart when measuring energy expenditure across a group of young, healthy, free-living adults. According to these data, it seems that this device has potential for situations in which the use of a metabolic cart is not practical, and hence, nutrition professionals may find these devices to be advantageous in conditions of both research and practice. However, there are limitations at high rates of oxygen consumption, and it seems that this device should be validated under each specific condition of use.

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In Memoriam: This manuscript would not have been possible without the guidance of Dr. Paul Flakoll. Dr. Flakoll passed away in December 2005 after a valiant battle with cancer. Dr. Flakoll was an inspiration to all those involved with this project. His friends and colleagues continue to champion his passion for nutrition research related to obesity and type 2 diabetes.

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