Concordance evaluation of a nutrition self-assessment app and clinical experts in estimating energy requirements and deficits among ONS consumers

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Running title: App vs clinicians in ONS energy deficit assessment

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ABSTRACT

Background and Objectives: The Nutrition Self-Assessment App (APP), a novel smartphone-based tool, was developed to enable users of oral nutritional supplements (ONSs) to self-assess total energy expenditure (TEE) and identify energy deficits, providing personalized ONS recommendations. By integrating step-count tracking and dietary intake reporting, the app estimates physical activity levels and energy deficits. However, validation against clinician assessments is essential prior to large-scale implementation. **Methods and Study Design:** In this multicenter cross-sectional study (October–November 2023), TEE and deficits were evaluated using both the app and clinician assessments. Statistical analyses included paired t-tests, intraclass correlation coefficients (ICC), and Bland–Altman plots. Clinician satisfaction was measured via a 5-point Likert scale. **Results:** Among 423 ONS users, no significant differences were found between clinician- and app-derived estimates for TEE (1606.2 ± 287.2 vs. 1541.6 ± 300.5 kcal/day, $p > 0.05$) or energy deficits (610.4 ± 376.9 vs. 600.1 ± 384.6 kcal/day, $p > 0.05$). Agreement was moderate for TEE (ICC = 0.66) and excellent for deficits (ICC = 0.94). Bland–Altman analysis showed 93.9% (397/423) of deficit differences within 95% limits of agreement. Clinicians rated the app as "very satisfied" (46.1%) or "fairly satisfied" (37.1%) for most participants. **Conclusions:** The app demonstrated moderate agreement with clinician assessments for TEE estimation, while showing high agreement in energy deficit estimation. These findings validate its potential reliability as a supportive tool for ONS management. Its integration of activity tracking and dietary monitoring supports scalable implementation to improve ONS adherence.

Key Words: nutritional assessment, oral nutritional supplement, mobile application, energy expenditure, patient adherence

INTRODUCTION

Oral nutritional supplements (ONSs) are specialized medical formulations taken orally in addition to regular meals to correct dietary deficiencies. They may include enteral nutrition products, multivitamins, and trace elements, providing a balanced mix of nutrients to meet the body's nutritional requirements. ONSs are compatible with physiological processes and offer various benefits—nutritional, functional, clinical, and economic—for different patient populations in both hospital and community environments, making them the preferred choice for nutritional therapy.[1-4] ONSs are widely used to provide additional energy and nutrients along with regular diet for patients with various acute and chronic conditions, including coronary heart disease, geriatric fractures, cognitive impairment, tumors, chronic obstructive pulmonary disease, and sarcopenia as well as those undergoing hemodialysis, in both inpatient and home care settings.[1-4]

Although the benefits of ONSs for patients are well known, challenges remain in their clinical application in China. The awareness of ONSs remains limited, and its clinical value has not been fully recognized. The proper assessment of ONS requires collaboration among various healthcare professionals, including physicians, nurses, dietitians, and pharmacists. In addition, implementing ONSs requires regular follow-up—weekly for inpatients and biweekly for community or discharged patients—to ensure timely adjustments to ONS plans.[4] Patients' adherence to ONSs is frequently suboptimal due to multifactorial determinants spanning patient-related factors, clinical care teams, and systemic healthcare delivery constraints. This is evident in the frequent underconsumption of ONSs, which often falls below the recommended levels, resulting inadequate nutrient intake and reduced effectiveness of nutritional therapy.[5, 6]

Digital technologies, including smartphones and mobile applications, have become practical alternative tools for the comprehensive management of pharmacotherapy. Compared with conventional nutritional management methods, such as clinical assessments, these tools enable real-time monitoring of patients' conditions and medication adherence, provide reminders and positive reinforcement to enhance compliance, and improve timely access to healthcare services, thereby enhancing patients' overall management.[7] However, high-quality research on the utilization of digital technologies for ONSs remains limited. The Nutrition Self-Assessment App was developed to allow users to determine personalized energy expenditure, estimate energy deficits, and calculate ONS requirements based on user input. By incorporating step-count tracking and dietary intake reporting, the app facilitates real-time assessment and monitoring of ONS needs, supporting individualized nutritional management and improving the precision of interventions.

The aims of this study include (1) to compare the consistency between the assessments of Nutrition Self-Assessment App and clinicians in evaluating total energy expenditure (TEE) and energy deficits among ONS users and (2) to assess user satisfaction on the Nutrition Self-Assessment App. The results of this study provide strong evidence supporting the evaluation and clinical adoption of this application.

MATERIALS AND METHODS

Study participants

This study used a multicenter cross-sectional survey design and convenience sampling to recruit individuals at nutritional risk who were already using ONSs. Participants were recruited from the clinical nutrition departments of seven hospitals in Shanghai between October and November 2023. The inclusion criteria were as follows: participants (1) aged 18 – 80 years; (2) with a Nutritional Risk Screening (NRS2002) score ≥3, indicating nutritional risk;[8] and (3) with no intellectual disabilities who are capable of communicating effectively and using electronic devices. The exclusion criteria were as follows: participants (1) with severe heart, liver, or kidney dysfunction; (2) admitted to the intensive care unit (ICU); (3) with impaired intestinal function or inability to eat orally; (4) judged unsuitable by the researchers; and (5) who refused to participate.

This study strictly adhered to the principles of the Declaration of Helsinki and was approved by the ethics committee of Huadong Hospital Affiliated to Fudan University (No: 20230087) and institutional review boards of each participating center. All participants provided written informed consent.

Data collection

Clinicians calculated and recorded the TEE and energy deficits of the enrolled participants following their standard clinical diagnostic protocols. To assess the energy deficit, clinicians conducted a face-to-face inquiry regarding the participants' dietary intake over the past two weeks. This process relied on patient self-reporting of dietary intake, which was guided and verified by the clinician to ensure accuracy. Similarly, the app estimates energy deficits by asking participants to report "the percentage of current food intake compared with normal intake". Both approaches rely on self-reported, but the clinician's inquiry adds an professional guidance to enhance the accuracy of the reported dietary data.

The clinician assessment served as the reference method in this study. TEE was estimated using a weight-based predictive range combined with clinical judgment, as indirect calorimetry was not routinely employed in the participating clinical settings. Specifically, clinicians began with a predicted range of 25-30 kcal/kg/day, and the exact value with this range was determined by clinical judgment, considering factors such as the age, disease status, nutritional condition, and body composition. The exact value within this range was then determined by clinical judgment, synthesizing factors such as the patient's age, disease status (e.g., presence of metabolic stress), nutritional condition, and body composition.

Clinicians estimated TEE using a weight-based empirical range (25–30 kcal/kg/day) combined with individualized clinical judgment, which implicitly accounted for basal metabolism and physical activity without assigning explicit Basal Metabolic Rate (BMR) or physical activity level (PAL) values. This approach reflects real-world clinical practice in the participating centers, where indirect calorimetry was not routinely available and energy requirements were determined by synthesizing patient-specific factors, including age, disease-related metabolic stress, nutritional status, and body composition. Unlike the Nutrition Self-Assessment App, in which PAL is explicitly derived from step count, the clinician-based assessment incorporated physical activity implicitly through adjustment within the energy requirement range.

Therefore, specific PAL coefficients (e.g., 1.2 for bedridden or 1.3 for light activity) were not directly applied in the clinician assessment, and no fixed formula such as BMR × PAL was used to derive TEE. The clinician-based assessment of total energy expenditure (TEE) and energy deficits was conducted using a weight-based empirical approach combined with individualized clinical judgment, rather than through explicit application of predictive equations for BMR or fixed PAL coefficients. (Figure 1, Step 1). Simultaneously, under the supervision of a clinician, each participant used the Nutrition Self-Assessment App to determine and record their total energy requirements and deficits (Figure 1). Participants independently entered data such as sex, age, height, weight, and daily step count into the App, which automatically calculated the TEE (Figure 1, Step 1). TEE was calculated as PAL × BMR, with PAL derived from the step count using the 2023 Chinese Adult Physical Activity Level Prediction Equation (PAL = 1.17 + 0.000028 × steps).[9] BMR was calculated using the formula recommended by the 2023 Chinese Dietary Reference Intakes for measuring BMR [BMR (kcal/day) = 14.52 × Weight (kg) − 155.88 × Sex (Male = 0, Female = 1) + 565.79]. The TEE was then calculated by multiplying BMR by PAL: TEE = BMR × PAL. As BMR decreases with age, a correction factor was applied for participants aged ≥50 years (50 – 64 years: predicted BMR × 0.95; 65 – 74 years: predicted BMR × 0.925; ≥75 years: predicted BMR × 0.90).10 After completing Step 1, participants proceeded to screen for disease-related nutritional management needs (Figure 1, Step 2). If any special dietary requirements were identified, the App prompted the user to "consult a physician or clinical dietitian for professional nutritional supplementation advice" and terminated progression to Step 3.

Eligible participants without dietary restrictions requirements advanced to Step 3, where they entered “the percentage of current food intake compared with normal intake” (Figure 1, Step 3), indicating their estimated gap in daily dietary intake which translated into energy deficit percentage. The energy deficit amount (unit: kcal) was then calculated using TEE from Step 1, and the App displayed the recommended quantity of ONS to fill in the dietary intake gap (Figure 1, Step 4).

Clinicians monitored each participant’s use of the Nutrition Self-Assessment App, focusing on its effectiveness in supporting ONS users as the primary criterion. Satisfaction was measured on a 5-point Likert scale: 1 = not satisfied, 2 = slightly satisfied, 3 = moderately satisfied, 4 = fairly satisfied and 5 = very satisfied.

Statistical analyses

Statistical analyses were performed using SAS 9.4 and SPSS software. Continuous data conforming to normal distribution were expressed as mean ± standard deviation (SD), while non-normally distributed data were expressed as median (interquartile range). Paired t-test was used to evaluate significant differences between the TEE and energy deficits calculated by clinicians and the App Additionally, the agreement between the two methods was evaluated using (1) intraclass correlation coefficient (ICC), calculated with a two-way random-effects model, and (2) Bland–Altman analysis. All tests were two-tailed, with $p < 0.05$ indicating statistical significance.

RESULTS

Baseline characteristics

Between October and November 2023, 440 participants who met the inclusion criteria were enrolled. After excluding 17 participants, 5 because of missing participant identification numbers (IDs), 3 with duplicate IDs, and 9 with incomplete age or sex data, 423 participants were included in the final analysis. The mean age was 60.7 ± 17.5 years, with 188 females (44.4%), and the average body mass index (BMI) was 21.0 ± 4.2 kg/m2. The NRS2002 scores were distributed as follows: 219 participants (51.9%) scored 3, 120 (28.4%) scored 4, 70 (16.6%) scored 5, and 13 (3.1%) scored 6. The demographic characteristics are summarized in Table 1.

Differences in TEE and energy deficit assessments

The clinician-estimated TEE (1606.2 ± 287.2 kcal/day) were marginally higher than those calculated by the App (1541.6 ± 300.5 kcal/day), yielding a mean discrepancy of 64.6 ± 238.2 kcal/day (p >0.05). Similarly, for energy deficit quantification, clinician assessments (610.4 ± 376.9 kcal/day) and application (600.1 ± 384.6 kcal/day) demonstrated comparable results, with a nonsignificant inter-method difference of 10.3 ± 129.2 kcal/day (p >0.05) (Table 2).

Consistency of TEE and energy deficit assessments

The agreement between clinicians and the App was assessed using the ICC. The ICC for the TEE estimates was 0.66, indicating moderate agreement.[11] In contrast, the ICC for energy deficit estimates was 0.94, indicating excellent agreement (Table 2).

Bland–Altman scatter plots were generated using the TEE and energy deficits as the analysis metrics (Figure 2). Regarding TEE, the mean difference between the clinicians' and the App's estimates were 64.6 kcal (95% confidence interval [CI]: −541.0 to 411.7). A total of 406 participants (96.0%) fell within the 95% limits of agreement, demonstrating moderate agreement between the methods. Regarding energy deficits, the mean difference between the clinicians' and the App's estimates were 10.3 (95% CI: −268.4 to 247.8). A total of 397 participants (93.9%) fell within the 95% limits of agreement, indicating high agreement between the methods.

Satisfaction with the App

Satisfaction with the Nutrition Self-Assessment App was evaluated, with 195 participants (46.1%) rating it 5 (very satisfied), 157 (37.1%) rating it 4 (fairly satisfied), 59 (13.9%) rating it 3 (moderately satisfied), and 2.8% rating it ≤2. These findings indicate a high overall satisfaction level, with clinicians reporting that they were either fairly or very satisfied with the App for a majority of the participants.

DISCUSSION

Self-monitoring method with mobile health technologies has become an effective tool for the comprehensive management of many chronic diseases. However, research on self-assessment of ONS usage through digital technologies remains limited. Collection of dietary and physical activity data is a complex and challenge in nutritional assessment. In this Nutrition Self-Assessment App, patients only need enter simple data, like sex, age, height, and weight. This

App can track daily steps with a build-in function to estimate physical activity. Patients only need to report "the percentage of current food intake compared with normal intake" for dietary data. Moreover, patients can easily estimate TEE and energy deficit when there is dietary change, providing personalized recommendations on ONS usage. Therefore, this innovative and user-friendly app is an effective self-assessment tool for patients outside the hospital setting. In this study, energy deficit estimated by clinicians (610.4 ± 376.9 kcal/day) exceeds the recommended range of 400–600 kcal/day according to the ONS nutrition consensus,[4] indicating substantial energy deficits and guidance for optimal ONS use among these participants. The participants were recruited from hospitals in Shanghai, where economic conditions, medical resources, and health awareness are generally higher than those in other parts of China. Consequently, evaluating and adhering to ONS in other regions of China may present even more challenges.

Interestingly, the TEE estimated by clinicians and the app showed moderate agreement (ICC = 0.66), in contrast to the excellent agreement for energy deficits (ICC = 0.92 and 0.95) across the two high-risk groups (older adults and cancer patients). This moderate agreement for TEE may be attributed to the inherent complexity of estimating a patient's total energy needs, which involves not only BMR and PAL but also a range of individual factors such as disease status, nutritional condition, and physical activity fluctuations that can vary over time.[12, 13] The slight variability in clinician assessments could also stem from the different methods used by clinicians in evaluating TEE, which, as noted, are influenced by clinical judgment and local practices. Conversely, energy deficits are more directly influenced by the observed dietary intake relative to the estimated energy requirements, making them easier to assess with higher consistency. The high agreement observed (ICC = 0.94) further validates the APP's digital interface as a reliable method for collecting self-reported dietary data, comparable to face-to-face clinician inquiry, supporting its use in remote monitoring. This finding is consistent with previous studies suggesting that energy expenditure estimates are often subject to greater variability due to individual metabolic differences and the dynamic nature of physical activity.[14-16] Additionally, while the moderate ICC for TEE still indicates a reasonable level of agreement, it underscores the need for further refinement in TEE estimations and more standardized approaches in clinical practice. Future research could explore how refining the input parameters (such as more precise activity tracking or personalized metabolic factors) might improve the accuracy of TEE estimations in clinical settings.

ONSs are essential for vulnerable populations, including frail or anorexic older adults and cancer patients undergoing surgery, radiotherapy, or chemotherapy.[2, 17] Robust evidence from both China and Western countries consistently demonstrates that ONSs enhance survival rates and quality of life in cancer patients,[18-21] establishing them as a cornerstone of treatment for this group.[22] As malnutrition is a prevalent geriatric syndrome, ONSs have been shown to increase energy/protein intake, mitigate weight loss, improve nutritional/functional status, and reduce complications and mortality risks,[23-25] making them critical for malnutrition prevention and management in older adults. In China, older adults and cancer patients represent high-risk subgroups requiring targeted oral nutritional support. Subgroup analyses were conducted separately for older individuals (age >60 years, BMI <22 kg/m^2, n = 96) and cancer patients (tumor-associated, BMI <22 kg/m^2, n = 80). For the older cohort, clinician- and application-assessed TEE were 1511.0 ± 281.5 kcal/day and 1373.7 ± 207.8 kcal/day, respectively, with corresponding energy deficits of 678.9 ± 372.4 kcal/day and 648.8 ± 357.7 kcal/day, which show no statistically significant difference. The intraclass correlation coefficient (ICC) for energy deficit evaluation was 0.92, and Bland–Altman analysis revealed 92.7% of participants (89/96) within 95% limits of agreement, confirming strong consistency in this high-risk group. Similarly, in the cancer subgroup, clinician- and application-assessed TEE were 1560.0 ± 266.8 kcal/day and 1418.5 ± 199.0 kcal/day, with deficits of 738.0 ± 429.4 kcal/day and 708.0 ± 409.6 kcal/day (no significant difference). The ICC for deficit assessment was 0.95, and Bland–Altman analysis showed 92.5% (74/80) within agreement limits, demonstrating high consistency. These findings validate the App's alignment with clinician assessments in both populations, supporting its utility for patient self-monitoring and ONS dose adjustments in outpatient settings to improve adherence.

This study enrolled 423 participants from seven general hospitals in Shanghai, constituting the first multicenter, large-scale investigation into digital technology applications for ONSs in China. Multiple analytical approaches were utilized to assess the concordance between clinician-based and application-derived evaluations. However, the study's limitations should be noted. Its exclusive focus on secondary and tertiary hospitals in Shanghai may restrict the generalizability of findings to broader Chinese populations or diverse ethnic groups. Furthermore, as a multicenter cross-sectional study, it only captured consistency and satisfaction metrics at a single time point, necessitating future research to examine longitudinal data including sustained consistency and satisfaction across non-clinical settings.

Limitations

This study has several limitations. First, the nutrient database and energy gap algorithm within the Nutrition Self-Assessment App were not specifically adjusted for seasonal (e.g., winter vs. summer) or regional dietary patterns. The algorithm is designed to estimate a universal energy deficit based on the user's reported percentage of current versus normal intake, independent of specific food types. While this ensures simplicity and broad applicability, it does not account for variations in dietary composition that may occur by season or region. Second, the app relies on patients' self-reported input regarding their current food intake compared to normal intake, which is inherently subjective. This method can introduce variability, particularly among elderly and diseased populations, who may not accurately perceive their food intake. In this study, the app was designed with a reference image of recommended daily dietary composition to guide patients in making these self-assessments. While this approach offers a simple and efficient means for energy deficit estimation, it remains a crude metric compared to more detailed dietary assessments, such as 24-hour dietary recall or food diaries. However, these methods are often impractical for routine use due to their complexity and time requirements. Therefore, while the app's method may not be as precise as more formal dietary evaluations, it remains a practical and accessible solution for patients, particularly in outpatient and self-monitoring settings. Future studies could explore ways to refine this aspect of the app, possibly incorporating more accurate self-reporting tools or integrating more detailed dietary tracking capabilities.

In summary, the Nutrition Self-Assessment App demonstrated robust clinical validity through its moderate agreement with clinician evaluations, particularly in energy deficit estimation. The tool's ability to integrate step-count activity tracking with dietary intake analysis enabled accurate personalized recommendations for ONS users. Clinician satisfaction ratings further supported its practical utility, confirming its readiness for widespread implementation as a reliable self-assessment platform. While the results validate the App's current performance, future research could explore its longitudinal effectiveness across diverse patient populations to further enhance its clinical applicability.

CONFLICT OF INTEREST AND FUNDING DISCLOSURE

We disclose that C Zhu is employee and stockholder of Abbott. All other authors declare no competing interests.

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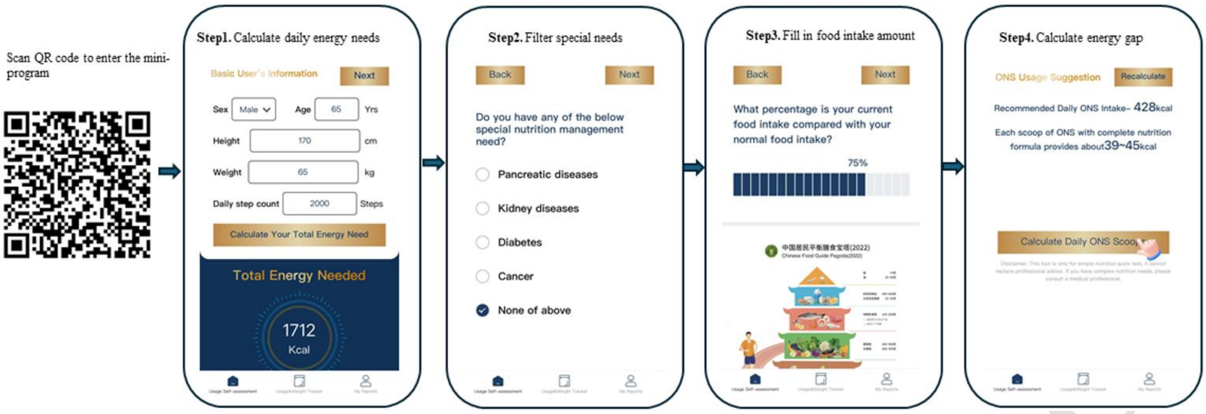

Figure 1. Operational diagram of the nutrition self-assessment app. Scan the quick response code to access the App. Under the supervision of a healthcare professional, oral nutritional supplement (ONS) users can enter their data on sex, age, height, weight, and daily step count, which the program uses to automatically calculate the total energy expenditure (TEE). Users then enter the percentage of their current food intake relative to their normal intake. The program calculates the energy deficit based on the TEE. Finally, the App recommends the required amount of ONS.

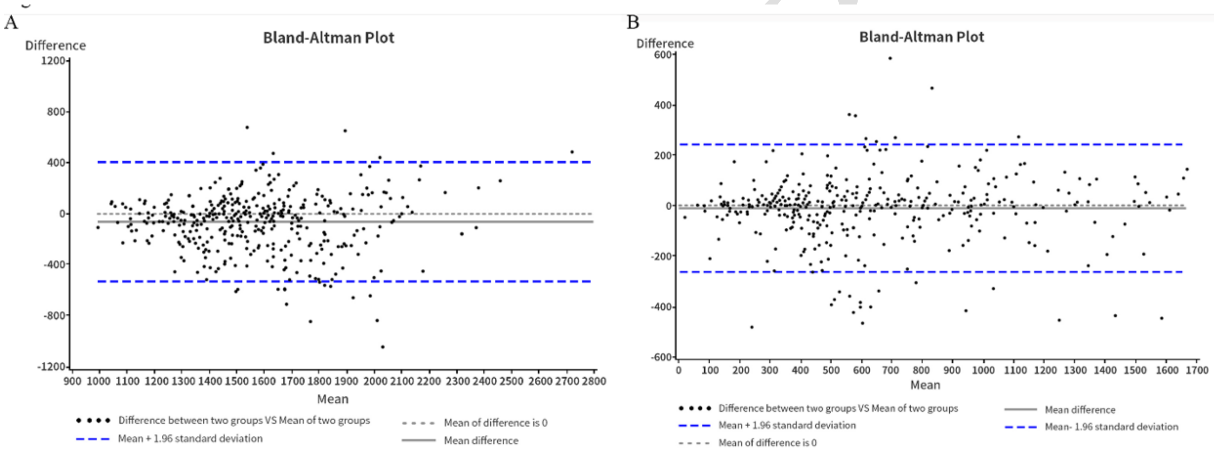

Figure 2. Bland–Altman analysis of the agreement between clinicians and the app in estimating (A) Total energy expenditure (TEE) and (B) Energy deficit. The X-axis represents the mean value obtained from the two methods for each ONS user, and the Y-axis represents the difference between the two methods

Table 1. Baseline characteristics of participants (n = 423)

Variable	Result
Age (years)	60.7 ± 17.5
18–45, n (%)	78 (18.5)
45–60, n (%)	97 (23.0)
60–80, n (%)	205 (48.6)
>80, n (%)	42 (10.0)
Female, n (%)	188 (44.4)
BMI (kg/m^2)	21.0 ± 4.2
Patients with tumors, n (%)	184 (43.5)
Nutritional Risk Screening (NRS2002) Score, n (%)	
3	219 (51.9)
4	120 (28.4)
5	70 (16.6)
6	13 (3.1)

BMI, body mass index; NRS 2002, Nutritional Risk Screening 2002.
Data are presented as mean ± standard deviation (SD) or number (percentage), as appropriate.

Table 2. Comparison of total energy expenditure and energy deficit estimates (n = 423)

Indicator	Overall (n = 423)
Physician Assessment	
Total energy expenditure (kcal/day)	1606.2 ± 287.2
Energy deficit (kcal/day)	610.4 ± 376.9
Application Assessment	
Total energy expenditure (kcal/day)	1541.6 ± 300.5
Energy deficit (kcal/day)	600.1 ± 384.6
Difference (Physician assessment − Application assessment)	
Total energy expenditure difference (kcal/day)	64.6 ± 238.2
≤5%, n (%)	159 (37.6)
>5% – <10%, n (%)	96 (22.7)
≥10%, n (%)	168 (39.7)
Energy deficit difference (kcal/day)	10.3 ± 129.2
≤5%, n (%)	162 (38.3)
>5% – <10%, n (%)	76 (18.0)
≥10%, n (%)	185 (43.7)
Agreement between physician and application assessment (ICC)	
Total energy expenditure (kcal/day)	0.66
Energy deficit (kcal/day)	0.94

ICC, intraclass correlation coefficient.
Data are presented as mean ± standard deviation (SD) or number (percentage). Differences are expressed as physician assessment minus application assessment.