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Assessing Resting Metabolic Rate in Overweight and Obese Adolescents With a Portable Indirect Calorimeter: A Pilot Study for Validation and Reliability

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Abstract

Background: Indirect calorimetry measured via the traditional indirect calorimeter is considered the "gold standard" for determining resting metabolic rate (RMR). Portable devices for assessing RMR are a less expensive option for measuring RMR in the clinical setting. This pilot study tested the reliability and validity of a portable device for measuring RMR, specifically in overweight and obese adolescents. *Materials and Methods:* Participants aged 17–19 years (n = 19) and ≥85th percentile on the Centers for Disease Control and Prevention body mass index growth curves for age and sex were recruited from a university campus. Participants completed testing on a traditional indirect calorimeter and a portable indirect calorimeter in a randomized order on 2 separate testing days. *Results:* A paired samples *t* test comparing the means of the portable device and the traditional indirect calorimeter found no significant difference ($P = .22$). The test-retest intraclass correlation coefficient for assessing RMR was 0.91, indicating reliability of the portable indirect calorimeter. Compared with measured RMR, the Mifflin–St Jeor equation demonstrated 37% accuracy, and the Molnar equation demonstrated 57% accuracy. *Conclusion:* This pilot study found portable indirect calorimetry to be reliable and valid for assessing RMR in an overweight and obese adolescent population. In addition, this study indicates that portable indirect calorimetry may be an acceptable option for assessing RMR in this population compared with the traditional indirect calorimeter or predictive equations. (*Nutr Clin Pract*.XXXX;xx:xx-xx)

Keywords

energy expenditure; obesity; resting energy expenditure; indirect calorimetry; energy metabolism; adolescent

Indirect calorimetry measured via the traditional indirect calorimeter is considered the "gold standard" for assessing resting metabolic rate (RMR).[1] However, while it is typically done in research settings, in clinical settings, dietitians often do not have access to indirect calorimetry, primarily due to cost and size.[2] In the absence of indirect calorimetry, pediatric dietitians often use predictive equations for RMR created for a pediatric population,[3–5] as well as equations that have been created for overweight and obese pediatric populations[5–7] to estimate appropriate calorie needs. There is currently no consensus as to which predictive equation to use in estimating RMR in overweight and obese youth. In addition, the predictive equations available introduce wide variability in estimating energy needs.[8–11] While predictive equations do account for factors such as height, weight, age, and sex, they do not account for other factors that are known to significantly affect RMR (eg, body composition, ethnicity, and critical illness).[2,12] Given that there is no consensus on the appropriate equation to use to accurately assess caloric needs in overweight and obese adolescents, and there is wide discrepancy among equations,[8–11] RMR should be measured rather than estimated.[1,13]

Portable devices for assessing RMR have been developed for use in the office and clinic setting and have been validated in adults and healthy-weight children.[2,12–16] An advantage to portable indirect calorimeters includes lower cost compared with the traditional indirect calorimeter. For example, a metabolic cart may be about 3–5 times more expensive than portable devices.[17,18] Another advantage is size and portability. A portable indirect calorimeter may be half the size of a traditional metabolic cart, weigh one-third less, and is more easily

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transportable for the clinical setting.[15,17,19,20] While these portable devices have been validated in obese and nonobese adults, as well as in nonobese children,[2,12,14–16] they have not been tested for reliability and validity in an overweight and obese adolescent population.

A traditional indirect calorimeter measures the volume of an individual's expired gas as well as the percentages of CO_2 and O_2 in that gas and is used to estimate RMR. Smaller portable devices do not have a CO_2 sensor and instead measure O_2 consumption, assuming that CO_2 production is about 85% of O_2 consumption. This is usually a valid assumption under resting conditions ~4 hours after a meal.[1]

While all portable devices assess RMR by measuring O_2 and estimating CO_2 production, there is variety in the types of portable indirect calorimeters available. Some devices are handheld[20] and have been extensively studied, but there are conflicting reports on their validity. Many[2,12,21,22] state that the handheld device is valid in both adults and children, while other studies suggest that it is not valid.[23–25] Other portable indirect calorimeters are not handheld and use technology that is similar to the traditional indirect calorimeter (ie, mixing chamber).[15,26] This "hybrid" technology of using a mixing chamber during gas analysis within portable indirect calorimetry may provide an advantage to the handheld device.[27,28] The KORR ReeVue (KORR Medical Technologies, Salt Lake City, UT) is representative of a class of portable indirect calorimeters designed to measure RMR and that is not handheld.[15]

Validation studies for portable indirect calorimeters have been conducted in healthy, ill, and obese patients; however, it is important to note that most of these studies have been done with an adult population.[2,21–24] To date, only one other study has validated a portable indirect calorimeter in a pediatric population, and this study did not include overweight and obese youth.[12] It is therefore important to validate these portable devices within this adolescent population specifically. While it is recommended to measure RMR with indirect calorimetry in the clinical setting[1,13] dietitians often do not have access to a traditional indirect calorimeter, often due to cost. Thus, it is clinically relevant to demonstrate validity and reliability of a less expensive option for measuring RMR such as a portable indirect calorimeter.

The purpose of this pilot study is to test the validity and reliability of a portable indirect calorimeter for measuring RMR in overweight and obese adolescents. The clinical relevance of this study is related to the importance of measuring RMR to help determine more individualized and accurate calorie needs when working with overweight and obese adolescents in the clinical setting. It is expected that in demonstrating validity and reliability of a portable indirect calorimeter for measuring RMR in overweight and obese adolescents, we will begin to establish the value of using this method for more accurate nutrition and weight management recommendations for this population in the clinical setting.

Methods

Participants were recruited from an urban university campus. They were aged 17–19 years and were ≥85th percentile body mass index (BMI; kg/m^2) for age and sex on the Centers for Disease Control and Prevention (CDC) BMI growth charts.[29] The Georgia State University Institutional Review Board approved the study, and informed consent was obtained from all participants. A reliability protocol was developed such that 2 separate testing days were scheduled, typically about 1 week apart, such that there would be no significant changes in body weight or BMI within that time frame. Research participants were also instructed to ensure that conditions prior to the test (ie, fasting) and on the day of testing were consistent on the 2 testing days. RMR testing was performed on both the traditional indirect calorimeter and the portable device. Throughout this article, the terms *traditional indirect calorimeter* and *portable indirect calorimeter* are used to describe each device. Order of testing was randomly assigned. If on testing day 1, a subject was randomly assigned to perform testing on the traditional indirect calorimeter first and testing on the portable indirect calorimeter second, this order was switched on the second testing day.

Indirect Calorimetry

Cosmed Quark CPET. The Cosmed Quark CPET (Rome, Italy) represents a class of indirect calorimeters (metabolic carts) designed for cardiopulmonary exercise testing and for assessing RMR.[19] The Quark model uses metabolic gas analysis systems that allow for automated breath-by-breath measurement of oxygen consumption (VO_2) and carbon dioxide production (VCO_2), technology that has been validated for over 15 years.[17] The system also uses mixing chamber gas analysis. The Quark system has been validated in both healthy and obese individuals.[30,31]

The Cosmed Quark CPET uses a paramagnetic oxygen sensor (O_2) with a noted accuracy of ±0.02% and is one of the most common types of O_2 sensors used.[17,19] The carbon dioxide sensor (CO_2) is a nondispersive infrared (NDIR) type and also has a noted accuracy of ±0.02%.[19] The Cosmed Quark dimensions are 17 × 30 × 45 cm with a weight of 5.9 kg. The RMR flowmeter is bidirectional and with flow accuracy of ±2%.[19] The Quark CPET is able to measure RMR for spontaneously breathing participants with a canopy hood. When the canopy hood is used, the flow rate is measured directly via a digital turbine flowmeter. Calibration is software assisted and includes room air, standard gas (4% CO_2 and 16% O_2), and flowmeter calibrations.

KORR ReeVue. The KORR ReeVue portable indirect calorimeter represents a class of portable devices developed to measure RMR and is not handheld (ie, by the patient), contains an oxygen sensor (O_2) for RMR measurement, and assumes an

RQ of 0.83 with the Weir equation used for metabolic rate calculation.[15,32] This technology has been validated in healthy and obese adults.[14,16,33,34] The KORR ReeVue uses a galvanic fuel cell O_2 sensor with a noted ±02% accuracy.[32] The flowmeter is a fixed-orifice differential pressure pneumotach type with a noted flow accuracy of ±2% (similar to the turbine). Its dimensions are smaller than the traditional metabolic cart at 20 × 30 × 10 cm and weighs about 2.3 kg.[32] The system also uses a mixing chamber technology, and calibration is automated as the device contains barometric, temperature, and relative humidity sensors in addition to the O_2 and flowmeter sensors.

Calibration of devices for the current study. For this study, the traditional indirect calorimeter was powered on for a warm-up of at least 15 minutes, and it was calibrated according to the manufacturer's guidelines. Before each test, calibration of the CO_2 and O_2 analyzers was performed using room air and a certified calibration gas (16% O_2/4% CO_2). Calibration of the RMR flowmeter was also performed using a certified 3-L calibration syringe. The portable indirect calorimeter was powered on, and after a brief warm-up period, the device self-calibrated. During this calibration, the device draws room air in and past the O_2 sensor. Once the O_2 sensor has been calibrated, the system zeroes while no gas is passing through the flowmeter. This calibration was done before each test.

RMR testing for each device. Research participants fasted overnight (approximately 8 hours) and had not exercised for at least 8–10 hours. Participants were also asked not to consume any caffeine-containing products or stimulants that could alter RMR. Prior to each test, participants were asked if they had adhered to the testing protocol previously described, and each participant's weight was also measured. As recommended, subjects performed each RMR test while seated in a semi-reclined position and in a quiet, lit room breathing as they would normally breathe.[1,35] Each research participant was in a resting state before testing began.[1,35] The same testing conditions applied for both the traditional indirect calorimeter and the portable indirect calorimeter and for each RMR test. The researcher who performed testing on each device was clinically trained in using the portable device and was also formally trained on the traditional indirect calorimeter by the company representative. For a given research participant, a single researcher did all testing.

Testing for the traditional indirect calorimeter was performed for about 15 minutes, and research participants breathed normally through a canopy hood. The first 5 minutes of data were discarded, and data between 5 and 15 minutes for the traditional indirect calorimeter were averaged as the final RMR data (kcal/d) for each subject. Steady state was achieved during this time frame (≤10% variability in VO_2 and VCO_2 over time). Testing for the portable indirect calorimeter was performed for about 10 minutes while participants breathed normally into a mouthpiece with expandable tubing and with a nose clip in place. A bacterial/viral filter was placed between the tubing/mouthpiece (MetaBreather; KORR Medical Technologies, Inc, Salt Lake City, Utah) and the air intake of the device. The RMR data (kcal/d) were provided by the device, usually after 10 minutes or when the portable indirect calorimeter established that the test readings were stabilized.

Predictive equations used to estimate RMR. The Mifflin–St Jeor equation is currently recommended for estimating RMR in healthy-weight and obese individuals.[36]

This equation was developed from a population of healthy-weight, overweight, and severely obese individuals aged 19–78 years.[36]

Mifflin–St Jeor equation for estimating RMR in kcal/d (all ages)[37]:

$$\text{Male}: 10\ (\text{wt.}) + 6.3\ (\text{ht}) - 5 \times\ \text{age} - 5$$

$$\text{Female}: 10\ (\text{wt.}) + 6.3\ (\text{ht}) - 5 \times \text{age} - 161$$

The Molnar equation was developed from a population of overweight and obese adolescents and has demonstrated accuracy in this population compared with other equations.[6,8,9]

Molnar equation for estimating RMR in kcal/d (all ages)[6]:

$$\text{Male}: 50.9\ (\text{wt.}) + 25.3\ (\text{ht}) - 50.3\ (\text{age}) + 26.9$$

$$\text{Female}: 51.2\ (\text{wt.}) + 24.5\ (\text{ht}) - 207.5\ (\text{age}) + 1629.8$$

Data were analyzed using SPSS (version 21; SPSS, Inc, an IBM Company, Chicago, IL). A paired samples *t* test was used to compare the 2 devices and to assess validity of the portable indirect calorimeter. The test-retest intraclass correlation was used to determine reliability for each device. Agreement between the 2 devices was assessed using Bland-Altman limits of agreement testing.[38] A paired samples *t* test was also used to compare the VO_2 of each device. Percentage of accurate predictions was calculated as the percentage of participants with estimated RMR within ±10% measured RMR with each device.

Results

Research participant descriptive data (n = 19) are provided in Table 1. Most research participants were female (84%) and African American (79%). Also, most participants (63%) were in the "obese" category as defined by BMI ≥ 95th percentile for age and sex on the CDC BMI growth charts. The reliability protocol data indicate that the mean ± SD days between testing days 1 and 2 were 6.7 ± 3.2. There were no differences in BMI between testing day 1 (33.2; interquartile range [IQR], 29.4–36.7) and testing day 2 (33.2; IQR, 29.6–37.1) (P = .80) or weight (lbs.) between testing day 1 (196.8; IQR, 177.0–223.5) and testing day 2 (197.6; IQR, 181.2–230.1) (P = .72). There

Table 1. Participant Descriptive Data (n = 19).

Variable	No. or Median (Interquartile Range)
Sex	
Female	16
Male	3
Race	
African American	15
Asian	1
White	3
BMI percentile[a]	
85th–90th	3
90th–95th	4
≥95th	12
Age, y	
18	5
19	5
20	9
Weight, lbs.	196.8 (177.0–223.5)
Height, in.	65.0 (63.9–67.5)
BMI,[b] kg/m^2	33.3 (29.4–36.7)

BMI, body mass index.
[a]85th–95th percentile = overweight; ≥95th percentile = obese.
[b]Severe obesity in adolescents: BMI ≥35 kg/m^2.

was one participant who, despite reporting that he followed pretesting conditions, did lose weight (4.5 pounds within 1 week) between testing days 1 and 2. Thus, as weight loss did not adhere to the reliability protocol, this participant's data were excluded from the reliability data analysis. The test-retest intraclass correlation coefficient for the traditional indirect calorimeter was 0.91 (95% confidence interval [CI], .76–.97) and was 0.91 (95% CI, .76–.97) for the portable indirect calorimeter, indicating that both devices were reliable. When comparing the RMR between the 2 devices, there was no significant difference (P = .22) (Table 2). Also, there was no significant difference in VO_2 when comparing the traditional indirect calorimeter and the portable indirect calorimeter (P = .08). The Bland-Altman analysis comparing the 2 devices (Figure 1) derived a mean bias of –32.1 kcal/d with limits of agreement –222 and 161 kcal/d. This demonstrates little bias and limits of agreement that are clinically acceptable.[39]

Compared with measured RMR (portable indirect calorimeter), the Mifflin–St Jeor equation demonstrated 37% accuracy (within ±10%). This predictive equation overestimated RMR (>110%) in 42% of participants and underestimated RMR (<90%) in 21% of the participants. The Molnar equation demonstrated 57% accuracy (within ±10%). This predictive equation overestimated RMR (>110%) in 21.5% of the research participants and underestimated RMR in 21.5% of the participants. Table 3 demonstrates the differences between measured and predicted RMR (estimated with the Mifflin–St Jeor and the Molnar equations) when comparing 2 research participants. Both the Mifflin–St Jeor and Molnar equations predicted very similar RMR estimations for participants of the same sex and with similar age, height, and weight (1668.6 kcal/d and 1667.4 kcal/d per Mifflin–St Jeor equation and 1506.4 kcal/d and 1602.8 kcal/d per the Molnar predictive equation). Average measured RMR for 1 participant was 1289.1 kcal/d, while the other participant's average measured RMR was 1828.2 kcal/d.

Discussion

While portable indirect calorimeters have been validated in nonobese and obese adults, this is the first study to test the reliability and validity of a portable device for assessing RMR in overweight and obese adolescents. The current pilot study demonstrates that there was no significant difference in measured RMR (kcal/d) when comparing the portable indirect calorimeter with a traditional indirect calorimeter. Data indicate that the portable indirect calorimeter used in this study is both reliable and valid compared with the traditional indirect calorimeter.

Many studies demonstrate the usefulness and improved accuracy of using portable devices compared with using predictive equations.[2,9,21,39–41] This current study, however, is the first to assess the validity and reliability of a portable device for assessing RMR specifically in an overweight and obese adolescent population.

This current pilot study also illustrates that while predictive equations may be fairly accurate in estimating RMR in a specific population as a whole, they do not account for individual variances. In this current study, accuracy of estimated RMR using predictive equations was quite low (37% and 57%) compared with measured RMR for overweight and obese adolescents. These results are similar to other studies.[8–11] This study also demonstrates a clinically relevant example of comparing predicted and measured RMR in 2 female individuals who "look" the same based on sex, height, weight, and age but are, in fact, very different. While the predictive equations would estimate each patient's RMR as essentially the same, actual measured RMR was approximately 200–390 kcal/d lower in one participant and 155–270 kcal/d higher in the other participant. The clinical importance of this is paramount and indicates that more accurate nutrition recommendations may be determined by measuring an individual's RMR rather than estimating RMR using predictive equations in overweight and obese adolescents. Others drew similar conclusions.[9,11]

This highlights the fact that predictive equations do not account for other factors that may influence RMR such as body composition or ethnicity. It is also interesting to note that in the example provided, one participant was African American while the other participant was white. This example highlights the importance of measuring RMR in the clinical setting, particularly in an overweight and obese adolescent population.

Table 2. Validity Data: RMR Measured in Overweight and Obese Adolescents via a Traditional Indirect Calorimeter and a Portable Indirect Calorimeter (n = 19).

Variable	Mean (SD)	Range
RMR traditional indirect calorimeter, kcal/d[a]	1662.7 (284.4)	1218–2262
RMR portable indirect calorimeter, kcal/d	1630.2 (315.7)	1188–2290
Measured RQ[b]	.79 (.04)	.71–.88
VO_2 traditional indirect calorimeter, mL/min[c]	242.9 (41.3)	176.2–326.9
VO_2 portable indirect calorimeter, mL/min	235.2 (45.1)	171.0 –330.5
RMR Mifflin–St Jeor predictive equation, kcal/d[d]	1751.7 (188.5)	1450.9–2107.4

RMR, resting metabolic rate; RQ, respiratory quotient; VO_2, oxygen consumption.
[a]No statistically significant difference in RMR between traditional indirect calorimeter and portable indirect calorimeter (P = .22).
[b]Measured via traditional indirect calorimeter. Portable indirect calorimeter assumes an RQ of 0.83.
[c]No statistically significant difference in VO_2 between traditional indirect calorimeter and portable indirect calorimeter (P = .08).
[d]Statistically significant difference between Mifflin–St Jeor predictive RMR and RMR measured with both a traditional indirect calorimeter (P = .05) and RMR measured with a portable indirect calorimeter (P = .02).

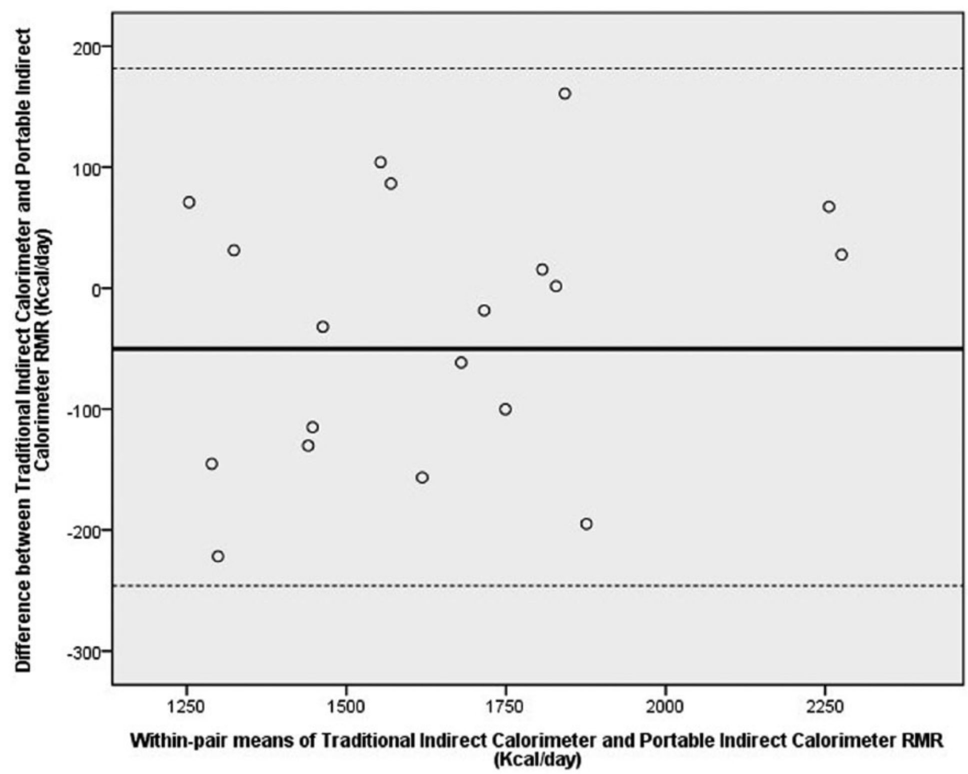

Figure 1. Bland-Altman plot of a traditional indirect calorimeter RMR vs a portable indirect calorimeter RMR. RMR, resting metabolic rate in kcal/d. The solid black line indicates the bias line; the dashed lines indicate the confidence interval lines.

The implications of these data are important for the clinical community. Currently, most dietitians base caloric targets for weight loss in overweight and obese adolescents on estimations derived from one of several equations, and there is currently no consensus on what is the best equation to use in this population. Data presented in this pilot study also highlight the importance of individual variance and that most commonly used predictive equations do not account for body composition, and none take into consideration ethnicity. Predictive equations do not capture the individuality of a patient's RMR. The present study suggests that using a portable indirect calorimeter is a more accurate means of assessing RMR in an overweight and obese adolescent population than using predictive equations.

A limitation is that the sample in this pilot study is small (n = 19). Thus, it is important to conclude that further confirmatory tests need to be done. Also, while recruitment occurred on a

Table 3. Measured and Predicted RMR: Comparison of Research Participants Similar in Sex, Age, Height, and Weight.[a]

	Research Participant	
Characteristic	A	B
Age, y	19	18
Sex	Female	Female
Race	African American	White
Height, in.	65	64.5
Weight, lbs.	196.4	196.8
Mifflin–St Jeor predictive equation, kcal/d	1668.6	1667.4
Molnar predictive equation, kcal/d	1506.4	1602.8
Average measured RMR, kcal/d[b]	1289.1	1828.2
Differences between measured and Mifflin–St Jeor predicted RMR, kcal/d	–379.6	+160.8
Differences between measured and Molnar predicted RMR, kcal/d	–217.4	+225.4

RMR, resting metabolic rate.
[a]Participants chosen based on sex, height, weight, and age and to demonstrate that predictive equations will estimate similar (if not the same) RMR for both participants. Actual, measured RMR was very different for each participant even though predictive equations estimated that they would have similar RMRs.
[b]Average measured RMR calculated as the average of the RMR measured via the traditional indirect calorimeter and the portable indirect calorimeter.

college campus with an equal distribution of 17- to 19-year-old males and females, most of the participants who volunteered for this study were females (16 of 19 participants). A strength of this study is that this is the first to evaluate reliability and validity of a portable indirect calorimeter for assessing RMR in overweight and obese adolescents.

Further research is needed to expand on the results found in this study and to cover a wider age range. Other validation studies have not noted results that differ based on sex,[21,25] thus there is no reason to consider that the current study would have differences based on this parameter. There may be differences in RMR assessment based on obesity status, as indicated in a recent study by Frankenfield and Coleman.[25] Therefore, it may also be worth exploring further the comparisons of RMR assessment with portable indirect calorimetry to predictive equations in overweight and obese children and adolescents.

Finally, these data demonstrate a clinically relevant finding such that measuring RMR with a portable indirect calorimeter can account for individual variances that predictive equations do not. Ultimately, this may lead to more accurate nutrition and weight management recommendations on an individual basis and possibly more successful outcomes when working with overweight and obese adolescent patients in the clinical setting.

Statement of Authorship

S. T. Henes and G. L. Warren contributed to conception/design of the research; S. T. Henes, A. Johnson, M. Toner, K. Mamaril, M. Kelkar, Y. Xiao, and G. L. Warren contributed to acquisition, analysis, or interpretation of the data; S. T. Henes, A. Johnson, and G. L. Warren drafted the manuscript; S. T. Henes, A. Johnson, M. Toner, K. Mamaril, M. Kelkar, Y. Xiao, and G. L. Warren critically revised the manuscript; S. T. Henes, A. Johnson, M. Toner, K. Mamaril, M. Kelkar, Y. Xiao, and G. L. Warren agree to be fully accountable for ensuring the integrity and accuracy of the work. All authors read and approved the final manuscript.

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