Original Article

Obtaining a formula that improves maximum oxygen consumption estimation in cycle ergometer exercise tests

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ABSTRACT

Objectives: To evaluate if the estimation of the maximal oxygen consumption (MO2C) in METs (metabolic equivalents) by means of the table proposed in the guidelines of the Spanish Society of Cardiology is a sufficiently reliable method when applied to the bicycle exercise test.

Material and methods: The MO2C in METs was obtained by gas-exchange analysis on bicycle ergometer tests in 97 healthy subjects (group I). It was compared with the estimate of METs using the table in which only watts and patient’s weight were included. A better-adjusted formula was validated in 289 subjects with normal exercise myocardial perfusion gated-SPECT (group II) using the introduction of clinical and ergonomic variables.

Results: In group I individuals a good correlation between METs estimated with the table and those obtained through gas-exchange analysis (CCI: 0.93) was observed. However, the best adjusted formula to estimate METs in group II subjects included watts, body mass index (BMI), age and gender (METs = 11.820 – 0.054 × age – 0.189 × BMI + 1.031 × gender + 0.020 × watts) (women: 0, men: 1). This formula allowed the reclassification of 46.9% of group II subjects into the category <5 METs versus the estimation by table.

Conclusions: Estimating the METs with the conventional table is reliable. However, the best adjustment in subjects with normal bicycle exercise SPECT was obtained when, in addition to watts and BMI, age and gender were also considered.

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Obtención de una fórmula que mejora la estimación del consumo máximo de oxígeno en las pruebas de esfuerzo con bicicleta ergométrica

RESUMEN

Objetivos: Valorar si la estimación del consumo máximo de oxígeno (CMO2C) en MET (unidad metabólica) mediante las tablas propuestas en las guías de la Sociedad Española de Cardiología (SEC) es un método suficientemente fiable cuando se aplica a las pruebas de esfuerzo con bicicleta ergométrica.

Material y métodos: Se obtuvo el CMO2C en MET por consumo de gases en bicicleta ergométrica en 97 sujetos sanos (grupo i) y se comparó con la estimación de los MET obtenida mediante tabla en la que solo intervinieron los vatios y el peso del paciente. Mediante la introducción de variables clínicas y ergométricas se obtuvo una fórmula con mejor ajuste para el cálculo de los MET validándose en 289 pacientes (grupo ii) con gated-SPECT de perfusión miocárdica normal.

Resultados: En los individuos del grupo i se observó una buena correlación entre los MET estimados con la tabla y los MET obtenidos mediante consumo de gases (CCI: 0.93). Sin embargo, la fórmula con mejor ajuste para la estimación de los MET en los pacientes del grupo ii incluyó los vatios, el índice de masa corporal (IMC), la edad y el sexo (MET = 11.820 – 0.054 × edad – 0.189 × IMC + 1.031 × sexo + 0.020 × vatios) (mujer: 0, hombre: 1). Esta fórmula permitió la reclasificación de un 46.9% de los individuos del grupo ii en la categoría <5 MET con respecto a la estimación por tabla.

Conclusiones: La estimación de los MET mediante la tabla convencional es fiable, aunque el ajuste óptimo, cuando se aplica a sujetos con gated-SPECT de perfusión miocárdica de esfuerzo normal, se obtiene al considerar, además de los vatios, el IMC, la edad y el sexo.

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Introduction

It has been more than 90 years since the first ergometric tests were performed,1–5 and exercise tests associated or not with imaging techniques continue to be fundamental diagnostic and prognostic studies in clinical cardiology.6–15 Maximum oxygen consumption (MO$_2$C) is generally estimated in metabolic units (MET) using tables including only exercise load and patient weight.16,17

In the stress myocardial perfusion gated SPECT it has been observed that if a determined level of tachycardization (80% compared to theoretical maximum) and MO$_2$C (5 MET) is not achieved, the test should not be considered as diagnostic since its sensitivity and negative predictive values are very low.18 On the other hand, the MET achieved in the stress test and scintigraphic criteria of severity play an important role in the risk stratification by myocardial perfusion gated SPECT.8 Thus, correct estimation of this parameter is essential from both a diagnostic and prognostic point of view.

On the other hand, different physiopathological studies have demonstrated that MO$_2$C not only depends on exercise load and the weight of the patient but also on other parameters such as age and gender.10–12 The aim of this study was to evaluate whether the estimation of MO$_2$C in MET obtained using the table recommended in the Guidelines of the Spanish Society of Cardiology (SEC) for bicycle ergometer stress tests is sufficiently reliable compared to direct measurement of gas consumption in healthy individuals. We also analyzed whether other variables, in addition to watts achieved and patient weight, allow better adjustment in patients with a suspected diagnosis of ischemic heart disease but with myocardial perfusion gated SPECT with normal effort.

Material and methods

We performed a prospective observational study including 97 healthy subjects (Group I) (25.1%) and 289 individuals with a suspected diagnosis of ischemic heart disease but with normal stress-rest myocardial perfusion gated SPECT (group II). All the subjects included performed a maximum stress test on an ergometer bicycle with continuous electrocardiographic and blood pressure monitoring. All the patients provided informed consent to participate in the study.

In Group I MO$_2$C was analyzed by the study of respiratory gases and was compared with the mean of the estimation of the MET by 3 observers using the table recommended by the SEC (Table 1).17 Interobserver variability in the estimation using the MET table was analyzed. Thereafter, we identified clinical and ergometric parameters to develop a formula with the best adjustment for the estimation of the MET. This formula was then validated in the 289 subjects in Group II with a maximum subjective negative stress test and with a normal gated-SPECT (with no evidence of ischemia and with a left ventricular ejection fraction >50%).

In the 97 subjects in Group I (mean age: 45.6±19.7 years; 42.3% women) the study was performed with an ergometer bicycle with an airflow transducer (Neumotac de Pitot), O$_2$ and CO$_2$ gas exchange analyzer, 12-lead electrocardiography, sphygmomanometer and pulsioximeter. Exercise began without workload and further increased in 10–30W/min, maintaining a speed of 60–70 revolutions per minute until the test was discontinued due to the inability to maintain the workload. Once the MO$_2$C had been obtained by gas exchange analysis, the MET were calculated by dividing O$_2$ consumption in mlO$_2$/kg/min by 3.5. Three experienced observers blinded to the MET obtained by gas exchange analysis, independently estimated the MET achieved using the table recommended by the SEC (Table 1).17 With the use of multiple linear regression analysis the best equation of regression was established for the calculation of MET using different clinical variables (age, gender, body mass index [BMI]) and ergometric data (watts achieved, maximum heart rate, maximum percentage of tachycardization, maximum systolic blood pressure and the product of maximum heart rate by maximum systolic blood pressure). Finally, we analyzed the concordance between the MET values estimated by the 3 observers and that obtained by gas exchange and the MET estimated by linear regression.

The study of the 289 subjects in Group II (mean age 62.7±11.6 years; 38.1% women) included an ergometer bicycle, 12-lead electrocardiograph and sphygmomanometer. Exercise began with an initial workload of 50 watts with increase in workload of 25 watts every 3 min. maintaining a speed of 60–70 revolutions per minute until discontinuation of the test due to inability to maintain the workload. The MET achieved were then estimated using the table recommended by the SEC (Table 1).17

Heart rate and blood pressure values were determined for all the ergometric tests every 3 min, at the end of the exercise and at the first, third and fifth minute post-exercise. The percentage of maximum tachycardization achieved was calculated in relation to the maximum theoretical tachycardization according to subject age (maximum heart rate/220 – age).

Statistical analysis

Continuous variables are expressed as the mean with standard deviation (±) and categorical variables are expressed as percentages. The continuous variables were compared using the Student’s t test for unpaired samples. For the analysis of the best equation of multiple linear regression (method ENTER; inclusion criteria p=0.05; exclusion criteria p=0.10) in Groups I and II, macro ALLSETS19 were used with 5 different indices: Mallows’ Prediction

Table 1

<table>
<thead>
<tr>
<th>Weight (kg)</th>
<th>12</th>
<th>25</th>
<th>50</th>
<th>75</th>
<th>100</th>
<th>125</th>
<th>150</th>
<th>175</th>
<th>200</th>
<th>225</th>
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<tr>
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<td>7.3</td>
<td>10.0</td>
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<td>16.0</td>
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<td>10.0</td>
<td>11.5</td>
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<td>9.3</td>
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<tr>
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<td>3.3</td>
<td>4.0</td>
<td>4.7</td>
<td>5.3</td>
<td>6.0</td>
<td>6.7</td>
<td>7.3</td>
<td>8.0</td>
<td>8.7</td>
<td>9.3</td>
<td>10.0</td>
</tr>
</tbody>
</table>

Source: Ruano Pérez et al.14
Criterion (Cp), Adjusted R Square ($R^2$ adj.), Akaike Information Criterion (AIC), Schwarz Bayesian Criterion (BIC) and $R^2$ Square ($R^2$). For the study of concordance we used the intraclass correlation coefficient (ICC for absolute agreement and consistency), Passing and Bablok regression and the Bland and Altman method. The ICC was considered bad (<0.04), acceptable (0.4–0.75) and excellent (>0.75). Differences were considered significant with a p < 0.05. All the data were analyzed with the SPSS program for Windows, version 15.0 (SPSS Inc., Chicago, Ill) and MedCalc®.

The percentage of subjects was calculated and, according to the formula obtained, was reclassified into the following categories: <5 MET, from 5 to 8 MET, >8 MET. The formula obtained with the regression equation for the estimation of the MET in Group I was validated in the 289 subjects of Group II (Table 2). Good concordance was obtained ($R: 0.84; R^2: 0.71$; $R^2$ adj. 0.707; ANOVA F: 697.610; $p < 0.001$) between the MET estimated with the table and the values estimated with the regression equation (ICC: 0.82; CI 195%; 0.73 to 0.97; F: 49.161; $p < 0.001$) (Fig. 2). Concordance for the global population ($n = 380$) was excellent (ICC: 0.9; CI 95%; 0.78 to 0.94; F: 139.534; $p < 0.001$). Table 3 shows the reclassification of the patients into the categories <5 MET, 5–8 MET and >8 MET according to the regression equation in the group II subjects. The concordance between the MET obtained with the table and the values of the regression equation was low, particularly in the category <5 MET (53.1%). Thus, 46.9% of individuals were reclassified into the category of <5 MET due to overestimation of the MET using the table.

**Results**

Table 2 shows the clinical and ergometric characteristics of the 2 groups studied. Compared to Group I, the patients in Group II presented the oldest age and BMI and lower tachycardization (albeit considered bad (<0.04), acceptable (0.4–0.75) and excellent (>0.75). Differences were considered significant with a $p < 0.05$. All the data were analyzed with the SPSS program for Windows, version 15.0 (SPSS Inc., Chicago, Ill) and MedCalc®.

The best equation of linear regression ($R: 0.95; R^2: 0.9; R^2$ adj.: 0.89; Cp: 3.26; AIC: 3; BIC: 15) to estimate the MET value from the clinical and ergometric parameters was: MET = 11.820 – 0.054 × age – 0.189 × BMI + 1.031 × gender + 0.020 × watts (woman: 0, man: 1) (ANOVA, F 197.608; $p < 0.001$). Fig. 1 shows the Passing–Bablok linear regression analysis and Bland–Altman analysis between the MET estimated with the table among the 3 observers was very good (ICC: 0.98; C 195%; 0.96–0.98; F: 124; $p < 0.001$) and among the observers and that obtained by gas exchange (ICC: 0.93; C 195%; 0.83–0.97; F: 107.38 $p < 0.001$). Nonetheless, the MET estimated with the table was found to be overestimated compared to that obtained by gas exchange (9.6 ± 3.2 vs. 8.5 ± 2.9; $p < 0.001$, respectively) (Table 2).

The best equation of linear regression ($R: 0.95; R^2: 0.9; R^2$ adj.: 0.89; Cp: 3.26; AIC: 3; BIC: 15) to estimate the MET value from the clinical and ergometric parameters was: MET = 11.820 – 0.054 × age – 0.189 × BMI + 1.031 × gender + 0.020 × watts (woman: 0, man: 1) (ANOVA, F 197.608; $p < 0.001$). The best equation of linear regression ($R: 0.95; R^2: 0.9; R^2$ adj.: 0.89; Cp: 3.26; AIC: 3; BIC: 15) to estimate the MET value from the clinical and ergometric parameters was: MET = 11.820 – 0.054 × age – 0.189 × BMI + 1.031 × gender + 0.020 × watts (woman: 0, man: 1) (ANOVA, F 197.608; $p < 0.001$). Fig. 1 shows the Passing–Bablok linear regression analysis and Bland–Altman analysis between the MET estimated with the regression equation and the MET obtained by gas exchange in Group I. No significant differences were observed between the mean values of the MET obtained by gas exchange and the MET estimated by regression analysis: 28.04 ± 3.2 [CI 95%; 7.9–9.1]; $p = 0.244$), showing excellent concordance (ICC: 0.94; CI 95%; 0.91–0.96; F: 37.391; $p < 0.001$).

**Discussion**

According to the results of the present study, the estimation of $\text{MO}_2\text{C}$ in MET using the table recommended by the SEC, which only considers the watts achieved during the bicycle ergometer stress test and the weight of the patient, is reliable. However, this estimation may be optimized with the use of a formula including the BMI, the age and gender of the subjects studied in addition to the watts achieved. Our results were obtained by comparing the $\text{MO}_2\text{C}$ values in MET by gas exchange with those estimated using the table in a control group of 97 healthy subjects and by thereafter applying the formula with the best adjustment to a group of 289 patients with suspected ischemic heart disease and normal stress myocardial perfusion gated SPECT. This prospective application suggests that although simple estimation with the table is reliable from a populational point of view, at an individual level it can be improved with the formula proposed. In addition, this formula allows reclassification of a notable number of individuals into the categories of <5 MET, 5–8 MET and >8 MET. The table tends to overestimate the MET, particularly in the first 2 categories, with 46.9% of the subjects being reclassified into the category <5 MET with the regression equation (Table 3).

Estimation of the MET achieved in a stress test is simple and practical and allows quantification of the energy used in different activities. A MET is defined as the quantity of O$_2$ consumed while seated resting and is equal to 3.5 ml (mlo$_2$/kg/min). Thus, work of 2 MET requires twice the metabolism consumed while resting, that is, 7 ml O$_2$/kg/min. By estimating the MET we can evaluate the functional capacity or tolerance to physical exercise in a progressive manner.

**Table 2**

<table>
<thead>
<tr>
<th>Clinical characteristics</th>
<th>Group I (n = 97)</th>
<th>Group II (n = 289)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Women (%)</strong></td>
<td>41 (42.3)</td>
<td>110 (38.1)</td>
<td>0.463</td>
</tr>
<tr>
<td><strong>Age (years)</strong></td>
<td>45.6 ± 19.7</td>
<td>62.7 ± 11.6</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td><strong>Weight (kg)</strong></td>
<td>68.4 ± 14.6</td>
<td>71.5 ± 11.3</td>
<td>0.054</td>
</tr>
<tr>
<td><strong>Height (cm)</strong></td>
<td>165.5 ± 10.9</td>
<td>164.5 ± 8.8</td>
<td>0.423</td>
</tr>
<tr>
<td><strong>BMI</strong></td>
<td>24.9 ± 4.7</td>
<td>26.4 ± 3.5</td>
<td>0.005</td>
</tr>
<tr>
<td><strong>Maximal HR (bpm)</strong></td>
<td>153.7 ± 20.7</td>
<td>144.9 ± 14.2</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td><strong>Maximal % of tachycardization</strong></td>
<td>88 ± 7.3</td>
<td>91.8 ± 7.1</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td><strong>Max. BP. (mmHg)</strong></td>
<td>187 ± 26</td>
<td>184 ± 26.9</td>
<td>0.345</td>
</tr>
<tr>
<td><strong>Max. HR product by max. BP.</strong></td>
<td>28,640.9 ± 4492</td>
<td>26,641.2 ± 4,616</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td><strong>Watts achieved</strong></td>
<td>164.3 ± 73.6</td>
<td>98.4 ± 35.5</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td><strong>MET by gas consumption</strong></td>
<td>8.5 ± 3</td>
<td>6.41 ± 1.5</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td><strong>MET with table</strong></td>
<td>8.5 ± 2.9</td>
<td>6.04 ± 1.6</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Max. HR: maximum heart rate; BMI: body mass index; bpm: beat per minute; Maximum BP: maximum blood pressure.

$p < 0.001$ (difference: 0.37036 [CI 95%; 0.266 to 0.474]).

$p < 0.001$ (difference: 1.1732 [CI 95%; 0.997 to 1.349]).
stress test and determine the physical activities in which a person may safely participate without exceeding a prescribed level of intensity. Activities consuming less than 5 MET are considered to be of low intensity, those using from 5 to 8 MET are of moderate intensity, and activity requiring a energy consumption greater than 8 MET is classified as being of high intensity.12

Application of the formula with the best adjustment obtained in our study allows greater precision in the estimation of the MET achieved with the ergometer bicycle. This is important from a diagnostic and prognostic point of view as demonstrated in many studies.8,21–23 The Aerobics Center Longitudinal Study (ACLS)21 reported a clear inverse relationship between the level of MO2C achieved and death in a large sample of healthy middle aged individuals. The greatest reduction in mortality was observed in subjects achieving 6 MET. In a follow up study of 6.2 + 3.7 years including a series of 6213 males undergoing a treadmill test Myers

Table 3

<table>
<thead>
<tr>
<th>Classification of the subjects in Group II into categories of MET achieved using the regression equation and the table.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MET with regression equation</strong></td>
</tr>
<tr>
<td>-------------------------------</td>
</tr>
<tr>
<td>&lt;5 MET, n = 81</td>
</tr>
<tr>
<td>5–8 MET, n = 164</td>
</tr>
<tr>
<td>&gt;8 MET, n = 44</td>
</tr>
</tbody>
</table>
et al. observed that the \( \text{MO}_2 \text{C} \) assessed in MET was the strongest predictor of mortality, being greater than the classical risk factors. For each increase in MET a increase of 12% in survival was observed. These results were recently corroborated in a series of 5314 older subject (65–92 years) followed for more than 8 years. In another series including 5672 patients suspected of having or diagnosed with ischemic heart disease undergoing myocardial perfusion gated SPECT and followed for more than 3 years, it was observed that although the SPECT information allowed more precise prediction of severe cardiovascular complications (cardiovascular death or acute myocardial infarction) it did not provide added prognostic data related to overall mortality to that of the clinical and ergometric variables including the \( \text{MO}_2 \text{C} \) estimated in MET, among others.

The tables recommended by the SEC and other scientific societies for the estimation of MET have the advantage of being easily applicable but have some limitations. On the one hand, they show discontinuous increases in both the watts achieved (stepwise increases of 25 W) and patient weight (stepwise increases of 10 kg) which do not allow precise calculation of intermediate values or the estimation of MET in patients with very high body weights. Some tables used by the American Heart Association to compare the MET achieved with different methods and exercise protocols do not even consider the weight of the patient in the estimation of the MET achieved. Moreover, these tables do not consider the age and the gender of the patients and a more precise approximation is not obtained on introducing the BMI instead of the weight of the patient. Individuals with the highest BMI tend to have higher oxygen consumption than subjects with a lower BMI. Even with the same BMI the percentage of fat in the body would explain differences in resting oxygen consumption. This would explain that the variables of gender and age could influence the estimation of the \( \text{MO}_2 \text{C} \) as we observed in our study on finding that the estimation of MET achieved with the ergometer bicycle provided the best adjusted formula. The watts achieved and the MET estimated by tables are lower in women and in older patients.

Application of the regression equation derived from our study would solve some of these limitations since this equation includes the exact watts achieved, the BMI instead of body weight and the
age and gender of the patient. Although the estimation of MET using a table is very simple and rapid in health care practice, in large series of clinical investigation the application described in the present study would allow greater precision and reproducibility in the estimation of M\textsubscript{O}\textsubscript{2}/C.

Limitations

Our results were found in a series of individuals from a single center with no evidence of heart disease. The regression equation for estimating MET in Group II should be validated by gas consumption in the same group of individuals similar to what was done in Group I. However, from a health care point of view this would be practically impossible in most hospitals. Future studies are needed to confirm if the estimation of MET using the formula developed in the present study is also applicable in patients with different types of heart disease.

Funding

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Conflict of interests

The authors declare no conflict of interest.

References