Abstract. The aim of this study was to assess the validity of VO2max prediction using retrograde extrapolation in a breath-by-breath (BxB) gas measurement system. A retrospective study was performed, analysing 31 incremental and maximal stress tests carried out in our laboratory, corresponding to male subjects who practised different sporting activities (age: 29.9 ± 14.45 years; height: 174.4 ± 6.5 cm; weight: 71.4 ± 7.2 kg). A linear regression of the first minute of recovery was used to obtain extrapolated VO2max data and, subsequently, a correction equation was applied that provided predicted VO2max values. Given the variability of data in BxB measurement systems, extrapolated values can be expected to vary significantly from those actually measured, but differences disappeared in the predicted values, which were almost identical to those measured. This method enables stress tests to be performed without having to record gas measurements until the end. It could be useful for the validation of specific field tests, measuring VO2 trackside after the test, during recovery.

Key Words: VO2max, Extrapolation, Retrograde, Breath by breath, Recovery.

Introduction

When maximal effort tests are performed in a laboratory incorporating the measurement of gases, there are frequently problems derived from the nuisance or discomfort endured by the athletes of wearing a facemask and the fact that, with some ergometers, the equipment makes it difficult to perform the technique correctly. Furthermore, there are some sports for which VO2max measurements cannot be taken in the laboratory since there are no adequate ergometers and they need (as the only option) reliable field tests. This is the case with swimming trials, for example.

For this reason, in the 1970s, different field tests were developed to estimate VO2max, validated by recording VO2 during recovery and then carrying out retrograde extrapolation using different techniques to estimate the maximum value.

Di Prampero et al. (Di Prampero, Cortili, Mognoni & Saibene, 1976) carried out the first estimation of oxygen cost in speed skating through retrograde extrapolation of the recovery curve for VO2 in a submaximal test, albeit it with only two subjects.

Leger et al. (Leger, Seliger & Brassard, 1979) conducted a study to determine the specificity of VO2max response among hockey players and runners, on an ice rink and a treadmill. Shortly afterwards, they performed another study to assess the retrograde extrapolation of VO2max (Leger, Seliger & Brassard, 1980), in which they aimed to compare the value obtained through the retrograde extrapolation of VO2
on the recovery curve at time zero of recovery with the value measured directly in a continuous multiple stage maximal test conducted in a laboratory. The method entailed connecting the subject, just after completing the test, to a Douglas bag to record VO2. This regression, extrapolated at time zero of recovery (coinciding with the end of the test), provided the estimated value for VO2max, related to the value obtained in the laboratory for a test of the same characteristics. The corresponding equations gave rise to validations of estimated consumptions using this type of field test. Hence, in 1982, Leger and Lambert validated the 20-m shuttle run test (Course Navette test) for the prediction of VO2max among adult men and women (Leger & Lambert, 1982).

Subsequently, other studies also used this type of estimation (Montpetit, Leger, Lavoie, & Cazorla, 1981; Costill, Kovaleski, Porter, Kirwan, Fielding, & King, 1985; Palicza, Nichols, & Boreham, 1987; Leger, Mercier, Gadoury, & Lambert, 1988; Ramsbottom, Brewer, & Williams, 1988; Sleivert, & Mackinnon, 1991; Sproule, Kunalan, McNeil, & Wright, 1993; Carré, Dassonville, Beillot, & Prigent, 1994; Stickland, Petersen, & Bouffard, 2003; Bandyopadhyaj, 2011;).

All these historic tests were carried out using a Douglas bag and, therefore, with averaged VO2 values usually obtained every minute (or in some cases every 20 or 30 seconds). This means that in order to obtain the regression, few points were used (usually 3 or 4) to avoid generating very long records.

However, no study has been done validating these regression measures with analyzers that use breath-by-breath (BxB) measurements. Since these measures involve clouds of points with large numbers of data in the same time unit, they could present differences in their predictability. Recently, studies have been carried out in swimmers with BxB equipment but estimating the VO2peak from recovery heart rate and with measurements of 20s (Chaverri, Iglesias, Schuller, Hoffmann & Rodríguez, 2016; Chaverri, Schuller, Iglesias, Hoffmann & Rodríguez, 2016; Rodríguez, Chaverri, Iglesias, Schuller & Hoffmann, 2017).

There has also been a work that extrapolates VO2max from second threshold data, although this does not resolve having to do the test with a face mask (Nunes, Silva, Machado, Menezes, Bocalini, Seixas et al, 1980).

The aim of this paper was to ascertain the validity of predicting VO2max by means of retrograde extrapolation in BxB gas measurement system.

Material and methods

Subjects

We performed a retrospective study analysing effort tests carried out in our laboratory along two years (2016 and 2017). A total of 31 incremental and maximal effort tests were exported from the laboratory’s database. All the tests corresponded to male subjects who practised different sporting activities (age: 29.9 ± 14.45 years; height: 174.4 ± 6.5 cm; weight: 71.4 ± 7.2 kg).

The inclusion criteria for tests to be considered in this study were: a) they were carried out on the same treadmill (Ergo Run Medical 8, Daum Electronic; Fürth, Germany); b) they were carried out using a progressive protocol in 1 minute increments until exhaustion; c) during the tests, records had been kept of breathing and gases using the same analyser (Breezesuit CPX made by MedGraphics; St. Paul, Minnesota, USA) and with breath-by-breath (BxB) records; d) there was a record of VO2 for at least 2 minutes of recovery.

Procedures

For each of the subjects, the stress test was reviewed to check the VO2max value, and these values were compiled in a table under the heading ‘measured VO2max’. Then, in each test, VO2 was analysed during recovery, verifying that the values all fit a linear regression for at least the first minute, although some of them, over a more prolonged period, presented an exponential fit. To standardise all the calculations, we chose to work with the first minute of recovery (certain to be during the rapid phase), obtaining the corresponding linear equation. Using this equation, in a graph where the Y axis represented VO2 in mL/min and the X axis represented time in minutes, the VO2max value was estimated, giving x the time value corresponding to the end of the test. This value was logged in the same table as above under the heading ‘extrapolated VO2max’.

In tests performed using BxB methodology, greater variability can be expected between the extrapolated and measured values of VO2max for various reasons.
The first is that the regression is performed with a point cloud instead of 3 or 4 average values; the second is that the end of the stress test is very different if we consider the presence of VO2max (existence of a plateau) or a peak value, since the existence of a plateau also implies the average value of a point cloud.

Accepting that this variability will affect the prediction value of the directly extrapolated value, we explored the degree of fit between the extrapolated and measured values in 31 subjects, obtaining the equation that links these two variables, which enabled us to use it as a correction equation for each of the extrapolated values. This corrected value was included in the same table under the heading «predicted VO2max».

Both extrapolated and predicted VO2max were individually compared with measured VO2max to check whether both measurements could be considered superimposable. To do this, we assumed that no correlation measure (e.g. Pearson) is valid for comparing the matching of measurements made by two devices (Altman, & Bland, 1983) since what is measured is the association between the two measurements, not their agreement. In other words, two series can have a correlation of 1 with any line, but only a line matching the so-called identity line (which passes through the origin and whose slope is 1) shows a perfect agreement between both variables (Altman, & Bland, 1983). For this reason, we followed the methodology proposed by Bland and Altman (Altman, & Bland, 1986) to specifically establish the degree of agreement between two measurements.

Statistical Analyses

First, a descriptive analysis was made reporting the mean and standard deviations (SD) of VO2max (measured, extrapolated and predicted). A 95% confidence level was established for all these analyses. To obtain a visual reference of the possible adjustment between measures, the linear relationship obtained from the extrapolated vs measured VO2max and predicted vs measured VO2max, was represented on a graph and their adjustment to the identity line was examined.

Bland-Altman Methodology

For this analysis, the difference between each pair of measurements was calculated for each individual (both for extrapolated vs measured VO2max and predicted vs measured VO2max) and these values were represented on a chart and compared to the mean of each pair of measurements. The 95% confidence limits calculated as the mean of all differences + 1.96 SD (upper limit) and – 1.96 SD (lower limit) were added to this chart.

In order to include a conventional statistic, a Student’s t-test for paired samples was applied to compare measured VO2max and predicted VO2max, accepting a value of p<0.05 as significant. Furthermore, a correlation study was performed (Pearson’s coefficient) between these values and measured VO2max.

**Results**

Table 1 provides the data for all the subjects corresponding to measured, extrapolated, and predicted VO2max, including the individual extrapolation equations.

| Subject | Equation | R² | Extrapolated Measured Predicted |
|---------|----------|----|-------------------------------|
| 1       | y = -41.22x + 26094 | 0.984 | 2865 | 2990 | 2991.5 |
| 2       | y = -32.30x + 12531 | 0.903 | 2928 | 3259 | 3069.5 |
| 3       | y = -30.56x + 13173 | 0.980 | 2580 | 2786 | 2744.2 |
| 4       | y = -24.67x + 12713 | 0.977 | 2720 | 2847 | 2874.9 |
| 5       | y = -27.25x + 10690 | 0.975 | 2770 | 2792 | 2921.6 |
| 6       | y = -59.06x + 27160 | 0.988 | 3582 | 3564 | 3679.8 |
| 7       | y = -47.01x + 26450 | 0.992 | 3316 | 3329 | 3431.4 |
| 8       | y = -72.8x + 12036 | 0.992 | 2821 | 2724 | 2961.8 |
| 9       | y = -388.34x + 14055 | 0.952 | 2024 | 3176 | 2972.0 |
| 10      | y = -40.40x + 20890 | 0.967 | 3799 | 3816 | 3882.4 |
| 11      | y = -36.95x + 13160 | 0.968 | 3012 | 3275 | 3147.6 |
| 12      | y = -20.85x + 10794 | 0.971 | 2452 | 2443 | 2624.7 |
| 13      | y = -32.62x + 10884 | 0.944 | 3443 | 3458 | 3550.0 |
| 14      | y = -9.02x + 16933 | 0.916 | 2582 | 2549 | 2746.1 |
| 15      | y = -18.57x + 13633 | 0.927 | 2896 | 3096 | 3039.3 |
| 16      | y = -25.64x + 12868 | 0.979 | 3712 | 3716 | 3801.2 |
| 17      | y = -13.42x + 10112 | 0.953 | 3064 | 3362 | 3196.1 |
| 18      | y = -15.93x + 18210 | 0.972 | 3713 | 3636 | 3802.1 |
| 19      | y = -66.2x + 34787 | 0.945 | 3416 | 3467 | 3524.8 |
| 20      | y = -140.15x + 30662 | 0.907 | 3212 | 3600 | 3525.2 |
| 21      | y = -152.81x + 29253 | 0.960 | 3733 | 3746 | 3820.8 |
| 22      | y = -869.9x + 31189 | 0.999 | 3365 | 3598 | 3477.2 |
| 23      | y = -141.63x + 28633 | 0.764 | 3420 | 3657 | 3528.5 |
| 24      | y = -127.78x + 28166 | 0.895 | 2993 | 3200 | 3129.8 |
| 25      | y = -191.47x + 39716 | 0.889 | 3719 | 4055 | 3807.7 |
| 26      | y = -177.04x + 39643 | 0.911 | 3703 | 3704 | 3792.8 |
| 27      | y = -137.49x + 28693 | 0.894 | 3807 | 4005 | 3889.9 |
| 28      | y = -9.68x + 21310 | 0.958 | 2928 | 3051 | 3069.1 |
| 29      | y = -116.61x + 25027 | 0.982 | 2637 | 2831 | 2787.4 |
| 30      | y = -153.1x + 34174 | 0.949 | 4166 | 4134 | 4225.1 |
| 31      | y = -146.76x + 32601 | 0.985 | 2813 | 3053 | 2983.2 |

The equation obtained relating the extrapolated and measured values in the 31 subjects, and which was used as the correction equation to obtain the predicted value, was $y = .94x + 335.26$ (Fig 1). The relationship between the measured and extrapolated VO2max is linear but
separates from the line of identity in its lower section.

Table 2 shows the mean and standard deviation values for measured, extrapolated, and predicted VO2max. Extrapolated VO2max presents significant differences (p=.0001) from the measured value, but once the correction has been made, this difference disappears (p=.91). Both data (extrapolated and predicted) present a very good correlation with the measured values (r=.95; p<.001).

Figure 2 shows how when the predicted VO2 is represented against the measured one, the linear relationship overlaps with the line of identity.

Figure 3 shows the Bland-Altman analysis with the differences between each pair of measurements, both for extrapolated vs measured VO2max and predicted vs measured VO2max, compared to the mean of each pair of measurements.

Table 2: Values for VO2max in the three situations studied

| Situation      | VO2max (mL/min) | SD  | p     | r     |
|----------------|-----------------|-----|-------|-------|
| Measured       | 3314.13         | 451.24 | .001  | .95   |
| Extrapolated   | 3190.26         | 457.55 | .0001 | .91   |
| Predicted      | 3314.00         | 427.21 | .91   | .95   |

Discussion

The main contribution of this study is to provide data regarding the retrograde extrapolation of VO2max based on recovery values in measurements taken using BxB equipment.

Given that classic studies on this subject (Montpetit, et al, 1981; Costill, et al, 1985; Paliczka, et al, 1987; Leger, et al, 1988; Ramsbottom, et al, 1988; Sleivert, & Mackinnon, 1991; Sproule, et al, 1993; Carré, et al, 1994; Stickland, et al, 2003; Bandyopadhyay, 2011) were conducted using Douglas bags, this paper provides a validation of breath by breath measurements, since extrapolations made using averaged values measured using a Douglas bag mean that usually only three or four values are used to perform the regression, whereas in BxB measurements, even one minute of recovery provides a cloud of at least 20 or 30 points.

Although both linear regression and exponential regression are valid for the prediction of VO2max based on retrograde extrapolation (Sleivert, & Mackinnon, 1991), this study has focused solely on...
performing a linear regression in the first minute of recovery, which has been possible thanks to the number of data provided by the BxB system, greatly simplifying the procedure as a result in order to maximise the number of possible applications.

The values for VO2max obtained directly by means of retrograde extrapolation of the first minute of recovery (3190.26 ± 457.55 mL/min) differed from the values measured during testing (3314.13 ± 451.54 mL/min), which would lead significant errors to be made. These differences confirm our initial idea that in BxB measurements, there is greater variability in the values for the reasons explained above. But if we apply by way of a correction the equation obtained from the linear relationship between the two values in the full group (Figure 1), we obtain almost an identical value (3314.00 ± 427.21 mL/min) to the one measured (Figure 2).

On the other hand, figures 1 and 3 confirm that the extrapolation from the first minute of recovery clearly overestimates the real value of VO2. In fact, figure 3A shows how all the differences between measured and extrapolated VO2 are positives. However, when the value is corrected (Figure 3B) the differences are positives and negatives with a value around 140 mL which means an error less than 5% for VO2max higher than three L/min.

Practical applications:

The possible applications for this estimation would be, among others:

a) The performance of stress tests without recording gas measurements (and therefore without having to use a facemask) until the end of the test. This application would be useful for athletes who feel that the facemask limits their real capacity, therefore making them unwilling to undergo such tests.

b) The measurement of VO2max by means of ergometers when it is somewhat tiresome having to keep a record of gas measurements throughout the entire test, for example a rowing or kayaking ergometer.

c) The validation of specific field tests, measuring VO2 trackside after the test, during recovery.

d) The measurement of VO2 immediately after swimming tasks.

For these applications we propose the following procedure: 1) to connect the subject to the gas analyzer just at the end of the test and collect recovery values; 2) to perform a linear regression using VO2 data from the first minute of recovery; 3) to obtain the VO2max extrapolated value in this equation giving x the time value corresponding to the end of the test; 4) to insert this value as x into the correction equation (y = 0.94x + 335.26). This equation could be substituted for any other equation obtained by each laboratory for specific populations.

Conclusions

It is possible to predict VO2max by means of retrograde extrapolation in BxB gas measurement system.

This extrapolation can be used in different circumstances, for which a specific procedure is proposed.

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