TRAINING

Metabolic Testing in the Office

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CARFAGNO, D.G., J. YUSIN, and L. KNOWLTON. Metabolic testing in the office. *Curr. Sports Med. Rep.*, Vol. 7, No. 3, pp. 163–170, 2008. *The three most commonly used metabolic tests are the Resting Metabolic Rate, Anaerobic Threshold Testing, and* $\dot{V}O_{2max}$. *For several decades, these metabolic tests have been confined to the setting of university-based physiology laboratories and cardiopulmonary environments, i.e., metabolic carts in the intensive care units. The information gathered is used as a research and clinical tool in evaluating metabolic activity in a variety of physiological states from a body at rest, to exercise (aerobic and anaerobic), in certain medical states like illness, fed/starvation, and medicinal or supplementation affective states. Over the last decade, as technology has improved, so have the metabolic testing carts. They have become widely available for mainstream use by a variety of health care professionals. The purpose of this article is to review these three tests and how they may be useful in a medical practice.*

INTRODUCTION

Physicians have long had the ability to perform diagnostic testing. The three main tests that we'd like to review are the basal/resting metabolic rate, $\dot{V}O_{2max}$, and anaerobic threshold.

BASAL/RESTING METABOLIC RATE TESTING

Basal metabolic rate (BMR) is the amount of energy expended while at rest in the post-absorptive state. This means that the digestive system is inactive, which requires about 12 h of fasting in humans. The energy in this state is sufficient only for the functioning of the vital organs. BMR decreases with age and with the loss of lean body mass (1). Increased cardiovascular exercise and muscle mass can increase BMR (2). Illness, previously consumed food and beverages, environmental temperature, and stress levels can affect one's overall energy expenditure, and therefore one's BMR (2,3).

Resting metabolic rate (RMR) is a less strict measurement than BMR. Both are evaluated via gas analysis through either direct or indirect calorimetry. RMR is more commonly used and equivalent to the BMR plus 10%, accounting for the thermic effect of food. The Harris-Benedict equation [1] also is an estimation via an equation using age, sex, height, and weight. Scientists J. Arthur Harris and Francis G. Benedict developed the Harris-Benedict Equation. Their work shows that by using the body surface area (weight divided by the height squared), along with the age and sex, and measurements of the oxygen and carbon dioxide via calorimetry, an estimation of one's metabolism can be measured (4).

$$\text{Men } h = 66.4730 + (13.751w) - (5.0033s) - (6.7550a)$$
$$\text{Women } h = 655.0955 + (9.5634w) + (1.8946s) - (4.6756a) \quad [1]$$

h = total heat production per 24 h at complete rest in kcal; w = weight in kilograms; s = stature (height) in cm; a = age in years.

Example 55 yr old woman, weighing 130 lb and standing 5'6", would have a BMR of 1266 kcal per day:

$$h = 655 + (9.6 \cdot 59) + (1.8 \cdot 168) - (4.7 \cdot 55) \quad [2]$$

Studies of energy metabolism using both methods (BMR and RMR) provide evidence for the validity of the respiratory quotient (RQ), which measures the substrate utilization of carbohydrates, fats, and proteins as they are converted to energy substrate units that the body can use for energy (5) (Figs. 1 and 2).

The RQ for glucose is 1.0, for fats is 0.696, and for proteins is 0.818. Why is the RQ important to know? During exercise there is a preferential way the three macronutrients are utilized. Protein catabolism has been estimated to supply 10%–15% of the total energy requirement during a 2-h training session. However, if a person's muscle glycogen supplies are low from previous exercise sessions, the amount of energy derived from protein catabolism could increase

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Oxygen Consumption ($\dot{V}O_2$, $\dot{V}CO_2$) Measurement System (or CPX)
Calibration Gases and Pressure Regulators Should include a true "Zero" gas,su ually 100% N2 and a "Span" gas, such as 16% O2 and 4%CO2.
Calibration Syringe , usually a 3-liter volume syringe
Exercise Device: Treadmills , Ergometers , rowing machine, etc.,
Patient Interface: a. Mouthpiece , 2-way valve and nose clip b. Stress Test Face Mask with headgear
Heart Rate Measurements or EKG system One channel (3-lead) minimum
Barometer
Hygrometer and Thermometer to measure relative humidity
Metabolic Calibrator / Simulator
Spirometer
Weight Scale and Height Measure
Valve Balancer, hangs breathing valve from overhead support
Typical pulmonary test supplies:
Mouthpieces and Noseclips
Breathing Tubes , to connect the exhalation valve to the mixing chamber. (in mixing chamber systems)
Sample Tubing , to connect the gas sample port to the gas analyzer input 1/8" ID and 1/16" ID respectively (in breath-by-breath systems)
Sterilizing/Disinfecting Solution to clean mouthpieces and breathing valves
Towels
Drink: Access to drinking water or juice

Figure 1. Metabolic testing equipment.

from 15% to 45% (6,7). The oxidative system (aerobic) is the primary source of ATP supplied to the body at rest and during low intensity activities and uses primarily carbohydrates and fats as substrates. Protein is not normally metabolized significantly, except during long starvation and long bouts of exercise (greater than 90 min). After the onset of exercise, as the intensity increases, there is a shift in substrate preference from fats to carbohydrates. During high intensity aerobic exercise, almost 100% of the energy is derived from carbohydrates (6,7).

MEDICAL CONSIDERATIONS

Food Intake

The total thermic effect of food (TEF) is approximately 7%–9% of energy consumed after a meal of 400–1200 kcal in non-obese and obese subjects. Studies in which metabolic rate is measured for 6 h after consumption of moderate to large meals reveal that 57% of the TEF has been expended at 3 h, 77% at 4 h, and 91% at 5 h. When a single measurement of RMR after a 4-h fast was compared with RMR after a 12-h fast, the 4-h measure was 74–139 $\text{kcal}\cdot\text{d}^{1}$ (mean 99 kcal) higher (8–10).

Alcohol Ingestion

As with food, alcohol also can increase metabolic rate (see Table 1) (11,12). Based on limited available studies, individual RMR increases of 1.1%–13.6% have been reported more than 95 min after ingestion of alcohol in healthy men (12) and mean RMR increases of 9% have been recorded 90–100 minutes postingestion in women (12).

Exercise

Energy expenditure increases with physical activity in proportion to the amount of work performed. After activity, energy expenditure returns towards baseline resting levels, but the recovery time varies as a function of the type, intensity, and duration of the activity and the physical fitness level of the individual. Thus it is important to allow ample recovery time after physical activity to obtain an accurate measure of RMR.

After walking or jogging on a treadmill at low to moderate intensity for 20–30 minutes, metabolic rate returns to

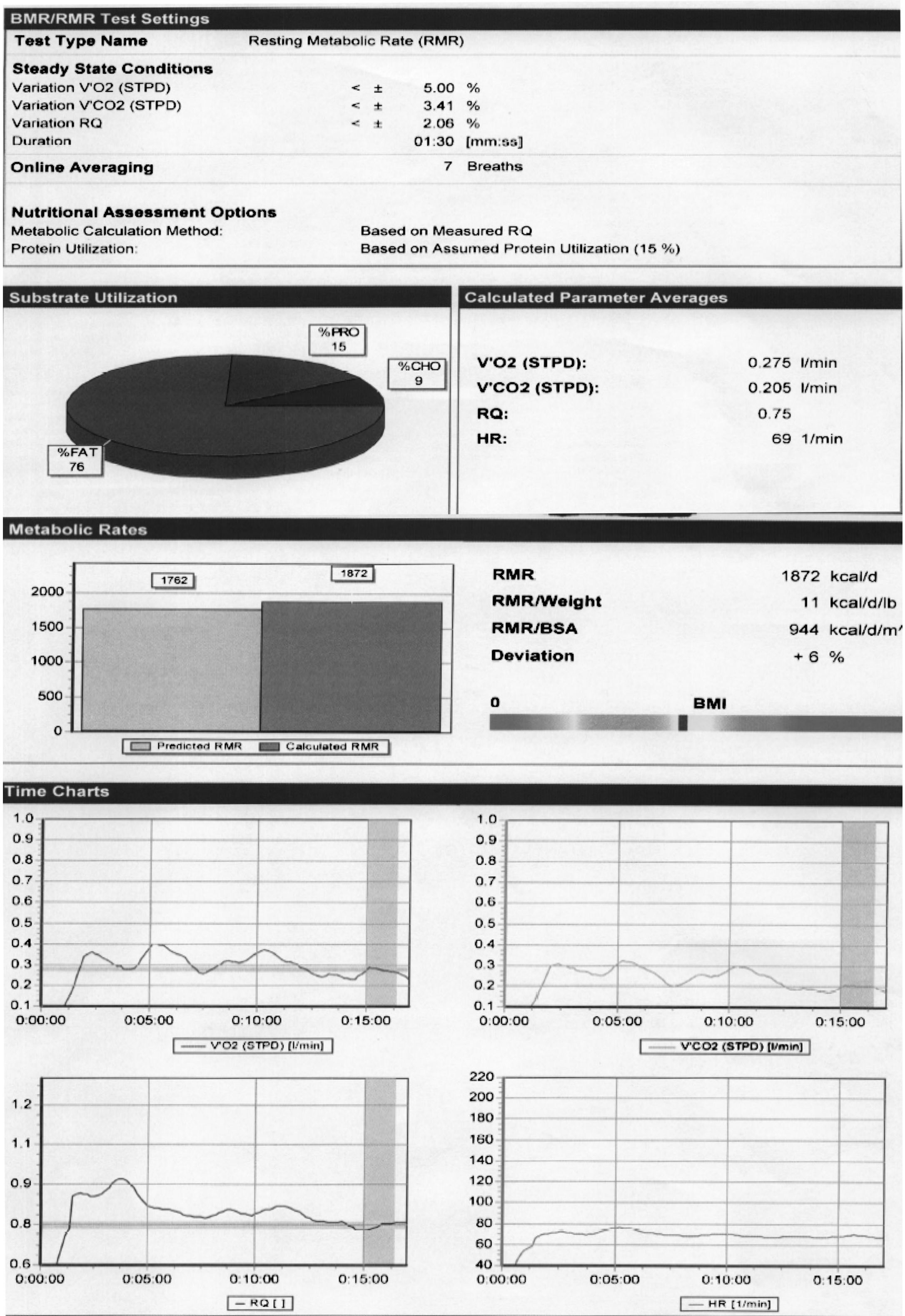

Figure 2. Sample resting metabolic rate test. Reprinted with permission from Scottsdale Sports Medicine Institute.

baseline RMR in 30–90 minutes (13–15). One study of trained and untrained individuals demonstrated that metabolic rate returned to resting levels within 60 min after 30 min of cycling at a higher intensity (70% of aerobic capacity) (7). The time to return to baseline RMR was more rapid in trained individuals (40 ± 15 min) compared with untrained individuals (50 ± 14 min) (7). In a different study, the recovery time after a 15-min high-intensity (70%

maximum oxygen consumption) and low-intensity (35% maximum oxygen consumption) exercise using a smaller mass of muscle (arms and shoulders rather than legs) was examined (16). Recovery time was 14 ± 6.5 min for high-intensity exercise and 5.7 ± 4.9 min for low-intensity exercise. Extending low-intensity exercise time to 30 min did not change recovery time (5.5 ± 4.4 minutes) (16).

Performing resistance exercise also elevates metabolic rate following cessation of exercise. Young women who performed a weight circuit at high intensity for 45 min had an average increase in metabolic rate of about 100 $kcal \cdot d^{-1}$ above RMR measured 90 min after exercise (17). Young men who performed a circuit weight training sequence at moderate or high intensity for 27 or 100 min had an average increase above RMR of about 250 and 360 $kcal \cdot d^{-1}$, respectively, measured at 90 min after completing the exercise (6,13). Even 14.5 h after a workout, metabolic rate was still around 100 kcal above baseline RMR (13). Forty-eight hours after 12 older (aged 59–77 yr) men completed single-leg knee extensions and bench press lifts (at 75% of each individual's three repetitions max), a 3% average increase (57 $kcal \cdot d^{-1}$) above RMR was recorded ($P < 0.001$) (6).

TABLE 1. Occupational applications for $\dot{V}O_{2max}$ testing.

Exercise stress (CPX) testing is frequently used in professions that require high physical demands, such as:
1. Firefighters
2. Police
3. Military
4. Rescue and disaster response teams
5. Miners
6. Steel mill workers
7. Divers
8. Professional athletes
9. Pilots
CPX testing in such professions may be used for:
1. Preemployment screening
2. Disability assessment and documentation
3. Routine fitness assessment
4. Rehabilitation assessment and documentation

Temperature

RMR is affected to variable degrees by moderate cold exposure or ambient room temperatures outside a comfortable zone (22°–25°C or 72°–75°F). In a study of 10 women and 10 men (aged 19–36 yr and body mass index [calculated as $kg \cdot (m^2)^{-1}$] 17–32), the individual change in RMR after 3 h of exposure to moderate cold (15°C or 59°F) compared with RMR at typical ambient temperature ranged from a decrease of 4% to an increase of 30% in winter and from a decrease of 12% to an increase of 24% in summer (18). At temperatures within the usual zone of comfort for human beings, no changes in RMR based on adjustment to ambient temperature are observed.

Caffeine

In healthy men, caffeine ingestion of 200–350 mg (equivalent to about 8–10 oz brewed coffee) resulted in group mean RMR increases of 7%–11% or 9–16 kcal between 30 min to 3 h after ingestion (Table 1) (19,20). At 30 min after caffeine ingestion, individual RMR changes ranged from −0.7% to 24.8% in lean and obese Japanese women (19–21) and over 90 min, group mean increases of 7.8%–15.4% were seen in white women (20). One study (21) offered a larger dose of caffeine in repeated smaller servings (*i.e.*, approximately 1250–1300 mg per 24 h) and measured the thermic effect of caffeine over 24 h in a respiratory chamber. After controlling for physical activity and TEF, the thermic effect of caffeine, on average, was 98–174 $kcal \cdot d^{-1}$ in lean women and women with obesity.

There is no direct evidence to determine when metabolic rate returns to true resting levels after caffeine consumption. The increase in metabolic rate was sustained at 3 h (18), but one study reported that after overnight abstinence from caffeine, RMR had returned to baseline levels (20). This suggests that a maximum of 12 h of abstinence will eliminate the thermic effect of caffeine, but that 3 h of abstinence comes close to baseline RMR.

Medications/Supplements

Weight-loss medications (*i.e.*, anorectic agents), such as sibutramine, may modestly reduce the RMR associated with a calorie-restricted diet for obese individuals; however, the data are conflicting (22–24). Three of the five studies demonstrated that the expected adaptive decline in RMR related to loss of metabolically active tissue was attenuated with sibutramine compared with placebo (especially when normalized to FFM). Only two of these studies showed statistical significance in RMR changes due to the variability in the outcome with a limited number of subjects (24–27). When counseling weight-loss patients, it is important for dietetics professionals to emphasize the influence of sibutramine therapy effect on appetite and satiety rather than a stimulation of energy expenditure.

Cardiovascular agents (propranolol, atenolol, carvedilol, and bisoprolol) have been shown to significantly reduce RMR by 4%–12%. This reduction may be potentially or clinically relevant in both the acute and chronic care settings, depending upon illnesses present and medical nutrition therapy goals (28).

Weight gain has been reported for patients taking antidiabetic agents for type II diabetes mellitus. One study indicated that the sulfonylurea glipizide subtly reduced RMR by 3.5% when compared with metformin for patients with type II diabetes (29). Two other studies indicate that metformin does not alter RMR in obese type II diabetics, and the observed weight gain associated with antidiabetic agents may be related to a reduction in urinary caloric losses by ameliorating glycosuria (29). Additional studies on these potentially relevant mechanisms for antidiabetic medication-induced weight gain are needed.

Long-term use of recombinant human growth hormone in growth hormone-deficient patients has been shown to increase RMR by 12% and is clinically relevant (30). Thyroxine therapy for hypothyroidism may cause a clinically relevant or potentially relevant increase in RMR, depending upon dosage. As much as a 17% increase in RMR can occur when treating significant hypothyroidism with levothyroxine (31).

Finally, there are potential exceptions and, in some cases, insufficient published data for some populations when addressing the effect of medications on energy expenditure. For example, elderly people may have an altered volume of distribution, impaired hepatic metabolism, or reduced urinary clearance of numerous drugs. Body fat also can serve as a depot and increase the volume of distribution for some drugs so that extent of adiposity may influence drug distribution and elimination. Therefore, definitive recommendations cannot be made for these types of individuals. Health professionals may need to consider these potential confounding factors when assessing the effect of pharmacotherapy upon energy expenditure.

Performing an RMR

Available data are somewhat limited regarding the minimum length of fasting and abstinence from caffeine, ethanol, nicotine, and exercise before attempting a measurement of RMR. Likewise, proper body posture and ambient conditions to ensure resting state have not been completely studied. It seems prudent and no great imposition on the client to conduct RMR measurements in a quiet, private space with temperature and humidity controlled at levels typical of most modern buildings. Light blankets should be available for clients who request them.

For measurements of RMR that require the strictest adherence to true resting state (*e.g.*, RMR research), subjects should have fasted for at least 6 h, should have abstained from caffeine overnight, from nicotine and alcohol for at least 2 h, from moderate physical activity for at least 2 h, and from vigorous physical activity for possibly 14 h. Measurement should be made with subjects in the supine or slightly elevated body posture. For research on TEF, studies should be conducted for a 6-h period, because shorter measures do not capture the entire TEF.

Prolonged periods (24–48 h) of abstention from physical activity or exercise before RMR measurement are not necessary for most individuals. A 2-h rest period following moderate, short-duration aerobic activity is sufficient to allow energy expenditure to return to resting levels. Vigorous resistance training has a more prolonged effect on metabolic rate and should be avoided for 14 h before RMR is measured.

The time needed to obtain an accurate measurement of RMR is only 5–10 minutes, after discarding the first 5 min of data, provided steady-state conditions can be obtained. Steady-state conditions have been established as a 10% CV in $\dot{V}O_2$ and $\dot{V}CO_2$ for healthy adults, or 5% CV in $\dot{V}O_2$ and $\dot{V}CO_2$ for critically ill patients (or a longer 30-min measure with 10% CV). When steady-state conditions are obtained, a single measurement of RMR is adequate to describe the resting caloric expenditure over 24 h. If steady state is not obtained, two to three repeated measures would increase the accuracy of the 24-h extrapolation.

Lactate Threshold Testing

Over the past 30 yr, lactate threshold (LT) has been used as an important measure for athletes. With improved technology, measuring lactate threshold has been becoming easier. The following section explains lactate threshold and how best to utilize it.

To fully understand the value of lactic acid threshold, one should be familiar with carbohydrate metabolism. Lactate is formed from the metabolism of glucose. Energy production results from the breakdown of glucose into two pyruvic acid molecules. Pyruvic acid interacts with either pyruvate dehydrogenase within the mitochondria of muscle leading to energy production, or it will encounter lactate dehydrogenase leading to the production of lactic acid. Lactic acid is later converted via oxidation into energy or transported back to the liver to form glycogen. Well trained muscles have a higher content of mitochondria, and thus are able to prevent further degradation into lactic acid (32).

As work increases, the demand for energy increase as well, leading to further carbohydrate breakdown into lactic acid. Lactate will begin to accumulate if the demand for energy exceeds the oxidation of lactic acid. This point, referred to as the lactate threshold, and can occur within 20–30 sec of extreme activity (32).

Studies performed on a few athletes during the 1970s determined that lactate began to accumulate when it reached a value of 4 $mmol{\cdot}L^{-1}$. Although further studies found that lactate threshold varies among individuals, ranging from 2 to 6 $mmol{\cdot}L^{-1}$.

Various terms have been used to describe LT, including onset of blood lactate accumulation (OBLA), maximal lactate steady state (MLSS), and anaerobic threshold. Lactic threshold seems to be the more accepted term.

In order to apply LT clinically, LT was later broken down further to LT1 and LT2 zones, where LT1 refers to aerobic threshold and LT2 refers to anaerobic threshold (the point where a significant rise of lactate occurs, *i.e.*, the LT) (VV). This led to developing a three-intensity zone model: low lactate zone, lactate accommodation zone (where blood lactate increases but is removed, and thus no accumulation), and the lactate accumulation zone (where blood lactate production is higher then maximal clearing, leading to lactate and eventual muscle fatigue) (33). These zones are accepted and used frequently (34).

LT units vary. The most common way to describe lactate threshold is via percentage of the $\dot{V}O_{2max}$. Other units include the actual velocity of the activity (*i.e*, $m{\cdot}sec^{-1}$) when lactic threshold occurs, and the actual lactate level when accumulation occurs (ranging from 2 to 6 $mmol{\cdot}L^{-1}$, as stated above).

There appears to be increasing evidence that conditioning occurs with much more success when intensity is applied (35). Athletes have used various parameters to gauge their intensity in various work outs. These parameters have included $\dot{V}O_{2max}$, and LT. Such workouts involve alternating high and low intensity above and below lactate threshold values (36). Using LT to develop intense conditioning programs has proved effective in children diagnosed with asthma. Following lactic threshold can be a cornerstone for improving conditioning in patients with various other ailments. Studies have supported that improved condition leads to a positive benefit in quality of life (37).

Studies also have shown that improved conditioning will lead to diminished individual LT values. This has been supported by studies involving MS and those with diabetes (38,39).

LT can be used as a diagnostic tool as well. Diagnosing a possible cause of dyspnea can be supported by lactate threshold value patterns, where a normal value can rule out a cardiac cause (40).

Over the years, the usefulness of the LT value has been debated. Critics state that the value of lactate threshold can change with a variety of parameters including diet, type of activity, and how measurement is obtained (41). Some studies point out LT measurements focus solely on circulating lactate without considering lactate present in nonworking muscles/liver (42). Thus it is important to control for various confounders: by using similar devices when following LT levels, controlling for diet, and measuring LT with a similar device.

Furthermore, it is important to remember that other measures are available to complement the LT findings. The American Thoracic Society/American College of Chest Physician position paper on Cardiopulmonary Exercise Testing addresses measuring lactate threshold in combination with other parameters, including $\dot{V}O_{2max}$ and how such information can help with diagnosing and treating cardiovascular, respiratory and musculoskeletal disorders (43).

Thus LT values can be used as a valid screening device. Further evaluation may need input from CPX and specialists.

$\dot{V}O_{2max}$ Testing

A $\dot{V}O_{2max}$ test is the gold standard, maximal exercise test to determine an individual's cardiorespiratory fitness level. Maximal oxygen ($\dot{V}O_{2max}$) is the product of the maximal cardiac output ($L{\cdot}min^{-1}$) and arterial-venous oxygen difference ($mL\ O_2{\cdot}L^{-1}$) and is expressed as liters of oxygen per minute or milliliters of oxygen per kilogram of bodyweight per minute. $\dot{V}O_{2max}$ is related to the functional capacity of the heart and how efficiently a person's body uses inspired oxygen. It is, therefore, the criterion measure of cardiorespiratory fitness.

Measuring $\dot{V}O_{2max}$

Open-circuit spirometry is used to directly measure $\dot{V}O_{2max}$. For the test, a subject breathes through a mouthpiece connected to a metabolic analyzer, and he or she wears a heart rate monitor. The analyzer measures the volume as well as the percentage of carbon dioxide and oxygen in the expired gas during a structured maximal exercise protocol. Knowing that room air contains 20.93% oxygen and 0.03% carbon dioxide, the amount of oxygen consumed can be computed after correction for barometric pressure, humidity, and temperature (44,45).

Equipment

The instrumentation for metabolic testing can vary greatly depending upon the type of testing to be performed, the reason for the test, the mission of the laboratory, and the desired accuracy. For example, a college teaching laboratory might be more interested in a basic low cost system, while a lab planning to publish its findings would be more interested in accuracy. Figure 1 lists equipment in approximate order of importance.

Normal $\dot{V}O_{2max}$ Values

$\dot{V}O_{2max}$ varies considerably in the population. The average young untrained male will have a $\dot{V}O_{2max}$ of approximately 3.5 $L{\cdot}min^{-1}$ and 45 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$ (46,47). The average young untrained female will score a $\dot{V}O_{2max}$ of approximately 2.0 $L{\cdot}min^{-1}$ and 38 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$ (47). These scores can improve with training and decrease with age, although the degree of trainability also varies very widely (48).

In sports where endurance is an important component in performance, such as cycling, rowing, cross-country skiing, swimming, and running, world class athletes typically have high $\dot{V}O_{2max}$. World class male athletes, cyclists, and cross-country skiers typically exceed 80 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$, and a rare few may exceed 90 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$ for men and 70 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$ for women. Three time Tour de France winner Greg LeMond is reported to have had a $\dot{V}O_{2max}$ of 92.5 at his peak — one of the highest ever recorded — while cross-country skier Bjørn Dæhlie measured at an astounding 96 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$ (49). It also should be noted that Dæhlie's result was achieved out of season and that physiologist Erlend Hem who was responsible for the testing stated that he would not discount the possibility of the skier passing 100 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$ at his absolute peak. By comparison, a competitive club athlete might achieve a $\dot{V}O_{2max}$ of around 70 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$ (47). World class rowers are physically very large endurance athletes and typically do not score as high on a per weight basis, but often score exceptionally high in absolute terms. Male rowers typically score $\dot{V}O_{2max}$ over 6 $L{\cdot}min^{-1}$, and some exceptional individuals have exceeded 8 $L{\cdot}min^{-1}$.

Several experiments of different types support the concept that, in trained individuals, it is oxygen delivery not oxygen utilization that limits $\dot{V}O_{2max}$ (48). By performing exercise with one leg and directly measuring muscle oxygen consumption of a small mass of muscle (using arterial catheterization), it has been shown that the capacity of skeletal muscle to use oxygen exceeds the heart's capacity for delivery. Thus although the average male has about 30–35 kg of muscle, only a portion of this muscle can be well-perfused with blood at any one time. The heart can't deliver a high blood flow to all skeletal muscle and still maintain adequate blood pressure. This limitation is analogous to the water pressure in your house. If you turn all the faucets on while trying to take a shower, the shower pressure will be inadequate because there is not enough driving pressure. Without getting in too deep on the hemodynamics, it seems that blood pressure is a centrally controlled variable; the body will not "open the valves" to more muscle than can be perfused without compromising central pressure and blood flow to the brain. The bigger the pumping capacity of the heart, the more muscle can be perfused while maintaining all-important blood pressure.

As further evidence for a delivery limitation, long-term endurance training can result in a 300% increase in muscle oxidative capacity, but only about a 15%–25% increase in $\dot{V}O_{2max}$ (49). $\dot{V}O_{2max}$ can be altered artificially by changing the oxygen concentration in the air. $\dot{V}O_{2max}$ also increases in previously untrained subjects before a change in skeletal muscle aerobic capacity occurs. All of these observations demonstrate that $\dot{V}O_{2max}$ can be dissociated from skeletal muscle characteristics.

Stroke volume, in contrast, is linearly related to $\dot{V}O_{2max}$. Training results in an increase in stroke volume and therefore an increase in maximal cardiac output. Greater capacity for oxygen delivery is the result. More muscle can be supplied with oxygen simultaneously while still maintaining necessary blood pressure levels.

It is important to also explain the contributing, or accepting, role of muscle oxidative capacity. Measured directly, oxygen consumption = cardiac output × arterial-venous oxygen difference (a-v O_2 diff). As the oxygen rich blood passes through the capillary network of a working skeletal muscle, oxygen diffuses out of the capillaries and to the mitochondria (following the concentration gradient). The higher the oxygen consumption rate by the mitochondria, the greater the oxygen extraction, and the higher the a-v O_2 difference at any given blood flow rate. Delivery is the limiting factor because even the best-trained muscle cannot use oxygen that isn't delivered. But if the blood is delivered to muscles that are poorly trained for endurance, $\dot{V}O_{2max}$ will be lower despite a high delivery capacity. When we perform $\dot{V}O_{2max}$ tests on untrained persons, we often see that they stop at a point in the test when their $\dot{V}O_{2max}$ seems to still be on the way up. The problem is that they just do not have the aerobic capacity in their working muscles and become fatigued locally prior to fully exploiting their cardiovascular capacity. In contrast, when we test athletes, they will usually show a nice flattening out of $\dot{V}O_2$ despite increasing intensity towards the end of the test. Heart rate peaks out, $\dot{V}O_2$ maxes out, and even though some of the best trained can hold out at $\dot{V}O_{2max}$ for several minutes, max is max and they eventually hit a wall because of the accumulation of protons and other changes at the muscular level that inhibit muscular force production and bring on exhaustion (50).

TABLE 2. Clinical applications for $\dot{V}O_{2max}$ testing.

1. Diagnosis of causes of exercise limitation
2. Exercise-induced asthma
3. Pre- and post-operative evaluation
4. Disability assessment functional capacity testing (METs)
5. Assessment of supplemental O_2 requirement Assessment of oxygen desaturation (SAO_2) during exercise
6. Evaluation of level of fitness/exercise prescription
7. Occupational fitness assessment (*e.g.*, police or firefighters) Preclearance for exercise/fitness/weight loss program
8. Evaluation of cardiac or pulmonary rehab
9. Evaluation of metabolic disorders
10. Evaluation of muscular disorders
11. Nutritional assessment
12. Resting energy expenditure (REE)
13. Fick cardiac output calculations
14. Cardiopulmonary rehabilitation
15. Measurement of physiological dead space and determination of the VD/VT ratio (Requires the $EtCO_2$ option)
16. Responses of cardiopulmonary variables in patients with cardiovascular disease (46,50)

Variable	Cardiac Disease	Lung Disease
$\dot{V}O_2$ peak	Decreased	Decreased
Anaerobic threshold	Decreased	Low or normal
Heart rate reserve	Decreased	Increased
Breathing reserve	Normal or increased	Decreased
O_2 pulse	Decreased	Normal or low
Exercise PaO_2	Normal	Normal or decreased
Exercise $P(Aa)O_2$	Normal or high	Increased
Exercise VD/VT	Falls normally	Fails to fall normally
ECG during exercise	Abnormal	Normal

Applying $\dot{V}O_{2max}$ Testing in Medical Practice

While a cardiac stress test is almost exclusively conducted for the purpose of evaluating a problem or suspected problem with the heart, there are several reasons for measuring oxygen consumption. Table 1 lists occupational applications of $\dot{V}O_{2max}$ testing while Table 2 lists clinical applications.

CONCLUSION

Metabolic testing has proven useful in the health and fitness and nutrition fields for many years. It also has provided information for physicians in the cardiopulmonary arena. Knowing what information they may provide, RMR, AT, and $\dot{V}O_2$ data can augment clinical decision-making for physicians when it comes to diagnosing and creating nutritional and exercise prescriptions for many patient populations on an everyday basis.

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