Accepted Manuscript

Title: Using Metabolic Equivalents in Clinical Practice

Author: Barry A. Franklin, Jenna Brinks, Kathy Berra, Carl J. Lavie, Neil F. Gordon, Laurence S. Sperling

PII: S0002-9149(17)31690-9
DOI: https://doi.org/doi:10.1016/j.amjcard.2017.10.033
Reference: AJC 22977

To appear in: *The American Journal of Cardiology*

Received date: 6-9-2017
Accepted date: 23-10-2017

Please cite this article as: Barry A. Franklin, Jenna Brinks, Kathy Berra, Carl J. Lavie, Neil F. Gordon, Laurence S. Sperling, Using Metabolic Equivalents in Clinical Practice, *The American Journal of Cardiology* (2017), https://doi.org/doi:10.1016/j.amjcard.2017.10.033.

Review

Using Metabolic Equivalents in Clinical Practice

Barry A. Franklin, PhD[a], Jenna Brinks[b], MS, Kathy Berra, MSN, NP[c], Carl J. Lavie, MD[d], Neil F. Gordon, MD[e], PhD, MPH, and Laurence S. Sperling, MD[f]

[a]Preventive Cardiology and Cardiac Rehabilitation, William Beaumont Hospital, Royal Oak, MI Oakland University William Beaumont School of Medicine, Rochester, MI

[b]Cardiovascular Medicine, William Beaumont Hospital, Royal Oak, MI

[c]Cardiovascular Medicine and Coronary Interventions, Redwood City, CA, Stanford Prevention Research Center, Stanford University School of Medicine (Emeritus)

[d]Department of Cardiovascular Diseases, John Ochsner Heart and Vascular Institute, Ochsner Clinical School-The University of Queensland School of Medicine, New Orleans, LA

[e] INTERVENT International, Savannah, GA

[f] Emory Heart Disease Prevention Center, Emory University School of Medicine, Atlanta, GA

Running Head: METs in Exercise Testing and Prescription

Corresponding Author:

Barry A. Franklin, Ph.D.
Director, Preventive Cardiology and Cardiac Rehabilitation
Beaumont Health – Royal Oak
Beaumont Health Center
4949 Coolidge Highway
Royal Oak, MI 48073

Telephone: (248) 665-5766
Fax: (248) 655-5751
E-mail: Barry.Franklin@beaumont.org

Abstract

Metabolic equivalents, or METs, are routinely employed as a guide to exercise training and activity prescription and to categorize cardiorespiratory fitness (CRF). There are, however, inherent limitations to the concept, as well as common misapplications. CRF and the patient's capacity for physical activity are often overestimated and underestimated, respectively. Moreover, frequently cited fitness thresholds associated with the highest and lowest mortality rates may be misleading, as these are influenced by several factors, including age and gender. The conventional assumption that 1 MET = 3.5 mL O_2/kg/min has been challenged in numerous studies that indicate a significant overestimation of actual resting energy expenditure in some populations, including coronary patients, the morbidly obese, and individuals taking beta-blockers. These data have implications for classifying relative energy expenditure at submaximal and peak exercise. Heart rate may be used to approximate activity METs, resulting in a promising new fitness metric termed the "personal activity intelligence" or PAI score. Despite some limitations, the MET concept provides a useful method to quantitate CRF and define a repertoire of physical activities that are likely to be safe and therapeutic. In conclusion, for previously inactive adults, moderate-to-vigorous physical activity, which corresponds to ≥3 METs, may increase MET capacity and decrease the risk of future cardiac events.

Key words: Metabolic equivalents; Cardiorespiratory fitness; Exercise prescription; Fitness and mortality

The term metabolic equivalents, or METs, indicates the oxygen requirements of varied activities. One MET equals the amount of oxygen the body uses at rest sitting, which approximates 3.5 mL O_2/kg/min. This expression of resting energy expenditure, originating from the work of Balke,[1] is traditionally considered to be independent of body weight and thus relatively constant for all persons. Thus, multiples of this value provide a simple, practical, and easily understood classification scheme to quantify relative levels of energy expenditure. For example, it is easier – and more meaningful – to explain to a patient that he has exercised at 3 times his resting metabolic rate than to indicate he has consumed 10.5 mL/kg/min. METs are also routinely used to describe an individual's aerobic capacity or level of cardiorespiratory fitness (CRF) and to prescribe activities that a patient can safely perform. The concept is easy to understand, and is often employed as an exercise training and activity prescription guide, and to categorize CRF. However, there are several inherent limitations, inaccurate assumptions, and common misapplications.

Energy expenditure of physical activity

The energy cost of many household, recreational, and occupational activities has been previously defined in terms of oxygen requirements, expressed as METs. In fact, to facilitate exercise and activity prescription, a compendium of physical activities has been developed to quantify energy expenditures based on the ratio of estimated or measured work metabolic rate to a standard resting metabolic rate.[2] Consequently, this resource is often used to identify and prescribe appropriate physical activities for varied populations. This involves recommending activities that are sufficiently below the highest MET level achieved during exercise testing. Walking at a leisurely pace uses about 2 to 3 METs, whereas faster walking speeds (e.g., 3.5 to

4.5 miles per hour [mph]) may approximate 4 to 5 METs. Singles tennis requires about 6 to 7 METs. In contrast, jogging and running typically require 8 to 10 or more METs, respectively.

Using METs to quantitate fitness

Peak or symptom-limited CRF can be directly measured or estimated during an exercise test, using either a treadmill or cycle ergometer. Direct assessment of CRF using ventilatory gas exchange responses may be particularly useful in risk-stratifying patients with heart failure who may be considered for heart transplantation, clarifying the functional impact and severity of valvular heart disease, differentiating cardiac versus pulmonary limitations as a cause of exertional dyspnea or impaired exercise tolerance, and in evaluating aerobic capacity more precisely due to the inaccuracies associated with estimating peak or maximal oxygen consumption.[3,4] Average healthy, young- to middle-aged adults generally have fitness levels ranging from 8 to 12 METs, indicating that they can increase their oxygen consumption (or energy expenditure) by 8- to 12-fold above their resting level. Patients with heart failure and those who are elderly or morbidly obese may have exercise capacities as low as 2 to 4 METs. Conversely, some elite endurance athletes can achieve 20 to 25 METs during maximal treadmill testing.

Our experience indicates that when CRF is estimated from the widely used Bruce treadmill protocol,[5] characterized by large aerobic increments per stage (≥2 METs), it is commonly overestimated, which may be minimized by ramping protocols that increase treadmill speed and incline continuously but in smaller increments. Aside from the fact that tight handrail holding is often permitted, reducing the aerobic requirement of treadmill walking while spuriously increasing the apparent MET expenditure, methodologic misapplications can also contribute to estimation error. A common mistake is to credit the patient for attaining a given stage of the Bruce protocol, even though they may have only partially completed their last attempted stage. For example, an apparently healthy woman stops exercising due to volitional fatigue after she has performed 30 seconds of stage 3 of the Bruce protocol (3.4 mph, 14% grade). The estimated MET capacity for this example is frequently listed as 9 to 10 METs, although the interpolated level of CRF is 7.5 METs.To provide more accurate estimates of the patient's functional capacity, we recommend minute-by-minute estimates of the MET capacity using the conventional Bruce treadmill protocol. Maximal oxygen consumption (VO_2 max) values were obtained in healthy men, women, and cardiac men using ventilatory expired gas analysis, expressed as mL/kg/min, and subsequently converted to METs (Table 1).[5,6] Stepwise multiple regression analysis, using the directly measured VO_2 max as the dependent variable, demonstrated that the duration of time (minutes) from the start of Stage I of this standardized test, which involves simultaneous speed/grade increments every 3 minutes, was the single most important determinant of the VO_2 max ($r^2 = 0.822$).[5]

Fitness thresholds and mortality

As a guideline, persons with fitness levels <5 to 6 METs generally have a poorer prognosis.[7,8] In contrast, fitness levels of 9 to 12 METs or higher are associated with a marked survival advantage,[9-13] even among men and women with and without abnormal risk factor profiles[14] or patients with known heart disease.[15] A moderate-to-high level of fitness, expressed as METs, confers a reduced risk of initial and recurrent cardiac events. For both primary and secondary prevention, each 1-MET increase in CRF is associated with a 15% decrease in mortality.[12,16] This reduction compares favorably with the survival benefit provided by commonly prescribed cardioprotective medications post myocardial infarction (e.g., aspirin, beta-blockers, angiotensin-converting enzyme inhibitors, and statins). Thus, a previously inactive, deconditioned patient who increases his/her MET capacity from 5 to 7 could reduce their mortality risk by ~30%.

In a seminal meta-analysis, Williams[17] reported a 64% decline in the risk of heart disease when moving from “poor” (bottom 20%) to “good” to “excellent” levels of CRF or aerobic capacity. In addition, a precipitous drop in risk is found when comparing the lowest quintile (#1) to the next lowest quintile (#2) (Figure 1). These data strongly support that poor fitness warrants consideration as an independent risk factor, and that the primary beneficiaries of an exercise regimen are those in the least fit, least active quintile. However, the above-referenced fitness thresholds may be misleading, as they are influenced by several factors, including age and gender. Accordingly, CRF levels decrease with age, commonly due to reductions in physical activity, peak heart rate, myocardial contractility, and the consequences of associated weight gain and chronic diseases. Healthy CRF cut points are also lower for women than men, due to their lesser muscle mass, hemoglobin levels, and stroke volume.

To further clarify age and gender-specific exercise capacity thresholds to guide assessment of mortality risk in individuals undergoing exercise testing for diagnostic and/or functional capacity assessment, Table 2 was developed using previously published data from the Aerobics Center Longitudinal Study,[18] the principal research asset of the Cooper Institute, Dallas, Texas, with specific reference to “good” (top 40%), fair and poor (bottom 20%) fitness levels. For both age and gender, the difference in achieving the cut point for “good” versus “poor” fitness approximates only 2 METs. Collectively, these data suggest that moving either from “poor” to “below average” fitness, or from “poor” (bottom 20%) to “good” fitness (top 40%), is likely to be achieved by moderate-intensity physical activity for a minimum of 30 minutes on 5 days each week or vigorous-intensity physical activity for a minimum of 20 minutes on 3 days each week. Other epidemiologic studies now support a cause-and-effect relation between improved CRF and reduced mortality,[19,20] rather than merely an association between these variables, especially when combined with relevant experimental and clinical data providing biologic plausibility.[21-22] Thus, it appears that even modest increases in CRF can have a favorable impact on population health.

Employing METs in exercise programming/prescription

Moderate-intensity physical activity is typically defined as 3–5.9 METs, whereas vigorous-intensity physical activity involves aerobic requirements ≥6 METs. Accordingly, moderate-to-vigorous intensity physical activity (MVPA), which corresponds to any activity ≥3 METs, has been consistently shown to reduce the health risks associated with numerous chronic diseases and the risk of developing them.[23] Other recent reports suggest that interventions that replace sedentary time with even brief periods of light-intensity physical activity (~2 minutes/hour) may confer a survival benefit.[24] Although traditional recommendations suggest that accumulated MVPA bouts should last 10 or more minutes to achieve the 30-minute daily minimum, recent studies suggest that even shorter periods of MVPA, accrued over time, can produce cardiovascular and metabolic health benefits.[25,26]

Regular endurance exercise or MVPA generally raises the level of CRF when performed for an appropriate duration/frequency. When initiating an exercise program, level walking at a 2 to 3 mph pace is strongly recommended, then gradually increasing walking speed over time. This is referred to as the “progressive transitional phase.”[27] Patients should be advised to stop exercise for symptoms of lightheadedness, persistent arrhythmias, angina, unusual shortness of breath, moderate-to-severe claudication or musculoskeletal discomfort. They should also be instructed to report new or worsening symptoms with exercise to their physician and should seek immediate medical attention for symptoms that do not resolve with rest. As a general guideline, the exercise intensity should feel “fairly light” to “somewhat hard” – rather than “hard” or “very hard.” For young or middle-aged adults, about 4 to 5 METs corresponds to moderate-intensity activity, and 6 to 8 METs for vigorous activity. Among healthy adults aged 65 and older, moderate-intensity activity approximates 3 to 4 METs, and vigorous exercise about 5 METs or higher.

There are, however, limitations that influence the use of METs when characterizing exercise intensity and estimating the energy expenditure of physical activities.[28-30] One limitation is the assumption that 1 MET = 3.5 mL/kg/min. Contemporary studies in some populations demonstrate that this value significantly overestimates directly measured resting oxygen consumption (VO_2) and caloric expenditure by, on average, 30% to 35%.[29,31] In our experience[32] and in the experience of others,[33] coronary patients and those on β-blocker therapy demonstrate a significantly lower resting metabolic rate as compared with the commonly accepted MET value. Similarly, our data,[34] and previous reports,[29,30] suggest a significantly lower resting VO_2, expressed as mL/kg/min, among coronary patients and the morbidly obese. Our obese study population (n = 64; 78% female) averaged 2.4 ± 0.5 mL/kg/min at rest, and most subjects fell between 2.0 and 2.6 mL/kg/min, corresponding to 57% to 74% of the standard “normative” value. These data have implications for classifying energy expenditure at submaximal and peak exercise. For example, the morbidly obese patient with a resting VO_2 of 2.4 mL/kg/min and a peak VO_2 of 16.6 mL/kg/min who is consuming 14.0 mL/kg/min would be classified as working at 5.8 METs (14.0/2.4) rather than the conventional estimate, that is, 4 METs (14/3.5). Moreover, her CRF would actually be 6.9 METs (16.6/2.4) as opposed to 4.7 METs (16.6/3.5). Depending on the ordering indication, underestimating CRF during peak or symptom-limited exercise testing may have significant implications for a patient’s plan of care, including incorrectly risk stratifying patients for pre-surgical clearance. Common variables that may potentially influence the resting metabolic rate are shown in (Table 3).[29,35]

The above-referenced findings also have relevance to exercise prescription and activity interventions in selected patient subsets (e.g., deconditioned, coronary, morbidly obese), including those with reduced levels of CRF, resting metabolic rate, or both. The threshold intensity for improving CRF in unfit individuals approximates only 30% of the VO_2 reserve, as follows: training $VO_2 = 0.3$ (peak $VO_2 - VO_2$ at rest) + VO_2 at rest.[36] For a patient with congestive heart failure taking a β-blocker, whose peak and resting VO_2 values are 15.4 and 2.5 mL O_2/kg/min, respectively, would suggest a minimum aerobic requirement of 6.4 mL/kg/min (i.e., 0.3 [15.4–2.5] + 2.5), corresponding to walking speeds ~1.0–2.0 mph. Thus, even “light” activity in this cohort, if maintained, may augment CRF and ultimately reduce mortality.

Another limitation is that MET values of selected physical activities represent average energy expenditure levels, and these levels may vary considerably among individuals, depending on age, body habitus, fitness, musculoskeletal integrity and whether the activity is performed in a competitive environment.[2] Metabolic demands are also highly dependent on speed and mechanical efficiency (skill). Activities that are less affected by skill include walking, jogging, and cycling. On the other hand, swimming, cross-country skiing, and tennis are associated with a wide range of energy expenditures. Environmental conditions, clothing and equipment can also influence the metabolic cost of activities.

Finally, the oxygen costs or MET requirements listed in the compendium of physical activities were derived from continuous steady-state work (≥3 minute bouts), whereas activities of daily living are often performed intermittently, rather than continuously. Accordingly, a patient who only completed Stage I of the conventional Bruce treadmill protocol (1.7 mph, 10%

grade), corresponding to a 5-MET capacity, might be counseled to refrain from gardening (a requirement of 5–6 METs), since presumably it represents maximal or supramaximal effort. However, if the activity is performed intermittently (i.e., 2 min work, 1 min rest), it can be accomplished at oxygen consumption levels well below those estimated for the task (Figure 2). Thus, by using the MET concept, one may considerably underestimate the patient's capacity for physical work.[37] This is particularly important when counseling patients about activities they enjoy and that will encourage them to be active such as gardening, swimming, dancing or walking the dog.

Estimating METs during level and graded walking

Oftentimes, the MET values provided by contemporary exercise equipment may differ considerably from the actual energy expenditure. The treadmill, however, is a notable exception. Because the mechanical efficiency of treadmill walking is relatively constant, the oxygen cost of treadmill walking is weight-dependent and at a given workload (speed and grade) requires approximately the same relative oxygen cost, expressed as METs, for all persons, regardless of age, fitness, or body weight.

The 'Rule of 2 and 3 mph' has been suggested as an assist in estimating "steady state" energy expenditure (at ~3 min or longer) during treadmill walking.[38] At a 2 mph walking speed at 0% grade, which approximates 2 METs, each 3.5% increase in treadmill grade adds 1 additional MET to the gross energy cost (e.g., 2.0 mph, 3.5% grade approximates 3 METs). For persons who can negotiate a 3 mph walking speed on level ground, which approximates 3 METs, each 2.5% increase in treadmill grade adds an additional MET to the gross energy expenditure (e.g., 3.0 mph, 5% grade approximates 5 METs).

Estimating activity METs from heart rate

Heart rate may be used to estimate METs during structured exercise or physical activity. Naughton[39] suggested that in sedentary subjects, each 10 beat per minute (bpm) increase in heart rate approximated a 1-MET increase in energy expenditure. Thus, a resting heart rate of 75 which increases to ~95 with walking (Δ = 20 bpm ~2 additional METs), is the equivalent of exercising at ~3 METs (1 MET [resting] + 2 METs = 3 METs). The larger the increase between the resting heart rate and the heart rate during exercise, the greater the energy expenditure. Wicks et al[40] reported a simple method for the prediction of oxygen uptake (METs) in patients with and without heart disease, including those taking beta-blockers, using the heart rate index equation (Table 4).

Evolution of Personalized Activity Intelligence. Using a series of reports over several years, researchers recently developed a new fitness metric, based on the changes in heart rate collected from the HUNT Fitness Study cohort involving >60,000 participants over a 20 year period, that monitors the intensity of physical activity.[41] Termed the personalized activity intelligence or PAI score, it is derived from the most recent 7 days of activity using the cumulative fluctuations in heart rate which, as detailed above, provides an approximation of the relative exercise intensity and associated energy expenditure. PAI is calculated based on the individual user's profile, incorporating age, gender, resting heart rate, and maximum heart rate. A unique feature is that it gives more credit for vigorous exercise than mild-to-moderate intensity activity. For example, an hour-long 3-mile walk that approximated nearly 6,000 steps earned 7 PAI, whereas a 30-minute intense bike ride for the same individual earned 56 PAI.[42] According to a recently published HUNT study analysis, after >1 million person-years of observations during an average follow-up of 26.2 years, men and women achieving a weekly PAI level ≥100 had a 17% and 23% reduced risk of cardiovascular disease mortality, respectively, compared with the inactive cohort,[41] although much of the benefit was obtained by achieving the first 50 PAI points. The results further suggest that this exercise dosage could increase the lifespan by at least 2 years, and up to 10 years for persons under 50. Collectively, these data, and other recent reports,[43,44] suggest that large daily fluctuations in heart rate and energy expenditure, expressed as METs, are not only associated with but appear to confer increased survival benefit and decreased health care costs.

In summary, physicians and allied health professionals should encourage patients to be physically active by engaging in recreational and leisure-time activities they enjoy and are comfortable performing. Dosing in 5-15 minute bouts, accumulated throughout the day, encourages regular physical activity and decreases sitting time. At all patient encounters, asking about minutes of daily MVPA is a strong message to patients.[45] How do we explain the practical significance of METs to our patients? By counseling them to increasingly incorporate "**M**oderate-to-vigorous **E**xercise, **T**uesday through **S**unday," or METs, into their lives.

Disclosures

The authors have no conflicts interest to disclose.

1. Balke B. The effect of physical exercise on the metabolic potential, a crucial measure of physical fitness. In: Staley S, Cureton T, Huelster L, Barry AJ, eds. Exercise and Fitness. Chicago: The Athletic Institute, 1960: 73–81.
2. Ainsworth BE, Haskell WL, Herrmann SD, Meckes N, Bassett DR Jr, Tudor-Locke C, Greer JL, Vezina J, Whitt-Glover MC, Leon AS. 2011 Compendium of Physical Activities: a second update of codes and MET values. *Med Sci Sports Exerc* 2011;431:575–1581.
3. Balady GJ, Arena R, Sietsema K, Myers J, Coke L, Fletcher GF, Forman D, Franklin B, Guazzi M, Gulati M, Keteyian SJ, Lavie CJ, Macko R, Mancini D, Milani RV; on behalf of the American Association Exercise, Cardiac Rehabilitation, and Prevention Committee of the Council on Clinical Cardiology; Council on Epidemiology and Prevention; Council on Peripheral Vascular Disease; Interdisciplinary Council on Quality of Care and Outcomes Research. Clinician’s Guide to cardiopulmonary exercise testing in adults: a scientific statement from the American Heart Association. *Circulation* 2010;122:191–225. doi: 10.1161/CIR.0b013e3181e52e69.
4. Ross R, Blair SN, Arena R, Church TS, Després JP, Franklin BA, Haskell WAL, Kaminsky LA, Levine BD, Lavie CJ, Myers J, Niebauer J, Sallis R, Sawada SS, Sui X Wisløff U; on beahalf of the American Heart Association Physical Activity Committee of the Council on Lifestyle and Cardiometabolic Health; Council on Clinical Cardiology; Council on Epidemiology and Prevention; Council on Cardiovascular and Stroke Nursing; Council on Functional Genomics and Translational Biology; and Stroke Council. Importance of assessing cardiorespiratory fitness in clinical practice: a

case for fitness as a clinical vital sign: a scientific statement from the American Heart Association. *Circulation* 2016;134:e653–e699. doi: 10.1161/CIR.0000000000000461.

5. Bruce RA, Kusumi F, Hosmer D. Maximal oxygen intake and nomographic assessment of functional aerobic impairment in cardiovascular disease. *Am Heart J* 1973;85:546–562.
6. American College of Sports Medicine. Guidelines for Exercise Testing and Prescription, 4th ed. Philadelphia, PA: Lea & Febiger, 1991:61.
7. Morris CK, Ueshima K, Kawaguchi T, Hideg A, Froelicher VF. The prognostic value of exercise capacity: a review of the literature. *Am Heart J* 1991;122:1423–1431.
8. Myers J, Kaykha A, George S, Abella J, Zaheer N, Lear S, Yamazaki T, Froelicher V. Fitness versus physical activity patterns in predicting mortality in men. *Am J Med* 2004;117:912–918.
9. Blair SN, Kohl HW III, Paffenbarger RS Jr, Clark DG, Cooper KH, Gibbons LW. Physical fitness and all-cause mortality: a prospective study of healthy men and women. *JAMA* 1989;262:2395–2401.
10. Myers J, Prakash M, Froelicher V, Do D, Partington S, Atwood JE. Exercise capacity and mortality among men referred for exercise testing. *N Engl J Med* 2002;346:793–801.
11. Gulati M, Pandey DK, Arnsdorf MF, Lauderdale DS, Thisted RA, Wicklund RH, Al-Hani AJ, Black HR. Exercise capacity and the risk of death in women: the St James Women Take Heart Project. *Circulation* 2003;108:1554–1559.
12. Kodama S, Saito K, Tanaka S, Maki M, Yachi Y, Asumi M, Sugawara A, Totsuka K, Shimano H, Ohashi Y, Yamada N, Sone H. Cardiorespiratory fitness as a quantitative

predictor of all-cause mortality and cardiovascular events in healthy men and women: a meta-analysis. *JAMA* 2009;301:2024–2035.

13. Fine NM, Pellikka PA, Scott CG, Gharacholou SM, McCully RB. Characteristics and outcomes of patients who achieve high workload (≥10 metabolic equivalents) during treadmill exercise echocardiography. *Mayo Clin Proc* 2013;88:1408–1419.
14. Wickramasinghe CD, Ayers CR, Das S, de Lemos JA, Willis BL, Berry JD. Prediction of 30-year risk for cardiovascular mortality by fitness and risk factor levels: the Cooper Center Longitudinal Study. *Circ Cardiovasc Qual Outcomes* 2014;7:597–602.
15. Vanhees L, Fagard R. Thijs L, Staessen J, Amery A. Prognostic significance of peak exercise capacity in patients with coronary artery disease. *J Am Coll Cardiol* 1994;23:358–363.
16. Boden WE, Franklin BA, Wenger NK. Physical activity and structured exercise for patients with stable ischemic heart disease. *JAMA* 2013;309:143–144.
17. Williams PT. Physical fitness and activity as separate heart disease risk factors: a meta-analysis. *Med Sci Sports Exerc* 2001;33:754–761.
18. ACSM's Guidelines for Exercise Testing and Prescription, 8th ed. Lippincott Williams and Wilkins, Philadelphia, PA, 2010:84–89.
19. Blair SN, Kohl HW III, Barlow CE, Paffenbarger RS Jr, Gibbons LW, Macera CA. Changes in physical fitness and all-cause mortality: a prospective study of healthy and unhealthy men. *JAMA* 1995;273:1093–1098.
20. Kokkinos P, Myers J, Faselis C, Panagiotakos DB, Doumas M, Pittaras A, Manolis A, Kokkinos JP, Karasik P, Greenberg M, Papademetriou V, Fletcher R. Exercise

capacity and mortality in older men: a 20-year follow-up study. *Circulation* 2010;122:790-797.

21. Thompson PD, Buchner D, Pina IL, Balady GJ, Williams MA, Marcus BH, Berra K, Blair SN, Costa F, Franklin B, Fletcher GF, Gordon NF, Pate RR, Rodriguez BL, Yancey AK, Wenger NK; American Heart Association Council on Clinical Cardiology Subcommittee on Exercise, Rehabilitation, and Prevention; American Heart Association Council on Nutrition, Physical Activity, and Metabolism Subcommittee on Physical Activity. Exercise and physical activity in the prevention and treatment of atherosclerotic cardiovascular disease: a statement from the Council on Clinical Cardiology (Subcommittee on Exercise, Rehabilitation, and Prevention) and the Council on Nutrition, Physical Activity, and Metabolism (Subcommittee on Physical Activity). *Circulation* 2003;107:3109–3116.
22. Leon AS, Franklin BA, Costa F, Balady GJ, Berra KA, Stewart KJ, Thompson PD, Williams MA, Lauer MS; American Heart Association; Council on Clinical Cardiology (Subcommittee on Exercise, Cardiac Rehabilitation, and Prevention); Council on Nutrition, Physical Activity, and Metabolism (Subcommittee on Physical Activity); American Association of Cardiovascular and Pulmonary Rehabilitation. Cardiac rehabilitation and secondary prevention of coronary heart disease: an American Heart Association scientific statement from the Council on Clinical Cardiology (Subcommittee on Exercise, Cardiac Rehabilitation, and Prevention) and the Council on Nutrition, Physical Activity, and Metabolism (Subcommittee on Physical Activity), in collaboration with the American Association of Cardiovascular and Pulmonary Rehabilitation. *Circulation* 2005;111:369–376.

23. Haskell WL, Lee IM, Pate RR, Powell KE, Blair SN, Franklin BA, Macera CA, Heath GW, Thompson PD, Bauman A; American College of Sports Medicine; American Heart Association. Physical activity and public health: updated recommendation for adults from the American Heart Association. *Circulation* 2007;116:1081–1093.
24. Beddhu S, Wei G, Marcus RL, Chonchol M, Greene T. Light-intensity physical activities and mortality in the United States general population and CKD subpopulation. *Clin J Am Soc Nephrol* 2015;10:1145–1153.
25. Fax JX, Brown BB, Hanson H, Kowaleski-Jones L, Smith KR, Zick CD. Moderate to vigorous physical activity and weight outcomes: does every minute count? *Am J Health Promot* 2013;28:41–49.
26. Glazer NL, Lyass A, Esliger DW, Blease SJ, Freedson PS, Massaro JM, Murabito JM, Vasan RS. Sustained and shorter bouts of physical activity are related to cardiovascular health. *Med Sci Sports Exerc* 2013;45:109–115.
27. Riebe D, Franklin BA, Thompson PD, Garber CE, Whitfield GP, Magal M, Pescatello LS. Updating ACSM's recommendations for exercise preparticipation health screening. *Med Sci Sports Exerc* 2015;47:2473–2479.
28. Jetté M, Sidney K, Blümchen G. Metabolic equivalents (METS) in exercise testing, exercise prescription, and evaluation of functional capacity. *Clin Cardiol* 1990;13:555–565.
29. Byrne NM, Hills AP, Hunter GR, Weinsier RL, Schutz Y. Metabolic equivalent: one size does not fit all. *J Appl Physiol* 2005;99:1112–1119.
30. Lavie CJ, Milani RV. Metabolic equivalent (MET) inflation ─ not the MET we used to know. *J Cardiopulm Rehabil Prev* 2007;27:149–150.

31. Gunn SM, van der Ploeg GE, Withers RT, Gore CJ, Owen N, Bauman AE, Cormack J. Measurement and prediction of energy expenditure in males during household and garden tasks. *Eur J Appl Physiol* 2004;91:61–70.
32. Dressendorfer RH, Franklin BA, Gordon S, Timmis GC. Resting oxygen uptake in coronary artery disease. Influence of chronic beta-blockade. *Chest* 1993;104:1269–1272.
33. Savage PD, Toth MJ, Ades PA. A re-examination of the metabolic equivalent concept in individuals with coronary heart disease. *J Cardiopulm Rehabil Prev* 2007;27:143–148.
34. Miller WM, Spring TJ, Zalesin KC, Kaeding KR, Nori Janosz KE, McCullough PA, Franklin BA. Lower than predicted resting metabolic rate is associated with severely impaired cardiorespiratory fitness in obese individuals. *Obesity* 2012;20:505–511.
35. Laquatra I. Energy. In: Escott-Stump S, Mahan K, eds. Krause's Food, Nutrition, and Diet Therapy. 9th ed. Philadelphia: WB Saunders, 1996: 17–30.
36. Swain DP, Franklin BA. VO_2 reserve and the minimal intensity for improving cardiorespiratory fitness. *Med Sci Sports Exerc* 2002;34:152–157.
37. Dafoe WA, Franklin BA, Cupper L. Vocational issues and disability. In: Pashkow FJ, Dafoe WA, eds. Clinical Cardiac Rehabilitation: A Cardiologist's Guide. Baltimore: Williams & Wilkins, 1993: 227–242.
38. Franklin BA, Gordon NF. Contemporary Diagnosis and Management in Cardiovascular Exercise. First edition. Newton (PA): Handbooks in Health Care Company, 2009:291.

39. Naughton J, Haider R. Methods of exercise testing. In: Naughton J, Hellerstein HK, eds. Exercise Testing and Exercise Training in Coronary Heart Disease. New York: Academic Press, 1973: 79–91.
40. Wicks JR, Oldridge NB, Nielsen LK, Vickers CE. HR index─a simple method for the prediction of oxygen uptake. *Med Sci Sports Exerc* 2011;43:2005–2012.
41. Nes BM, Gutvik CR, Lavie CJ, Nauman J, Wisløff U. Personalized Activity Intelligence (PAI) for prevention of cardiovascular disease and promotion of physical activity. *Am J Med* 2017;130:328–336.
42. Fowler GA. Stop counting 10,000 steps; check your personal activity intelligence. The Wall Street Journal. New York, January 20, 2016.
43. Lavie CJ, Arena R, Swift DL, Johannsen NM, Sui X, Lee D, Earnest CP, Church TS, O'Keefe JH, Milani RV, Blair SN. Exercise and the cardiovascular system: Clinical science and cardiovascular outcomes. *Circ Res* 2015;117:207–219.
44. George J, Abdulla RK, Yeow R, Aggarwal A, Boura J, Wegner J, Franklin BA. Daily energy expenditure and its relation to health care costs in patients undergoing ambulatory electrocardiographic monitoring. *Am J Cardiol* 2017;119:658–663.
45. Berra K, Manson JE, Rippe J. Making physical activity counseling a priority in clinical practice: the time for action is now. *JAMA* 2015;314:2617–2618.

LEGENDS

Figure 1. The risks of coronary heart disease and cardiovascular disease decrease in association with increasing quintiles of CRF or aerobic capacity. There is a precipitous drop in risk when comparing the lowest (poor) to the next-lowest quintile (below average) for aerobic capacity, with a 64% decline in the overall risk of heart disease from the least to the most fit. Interestingly, little or no additional benefit occurs when moving from quintile 4 to 5, that is, “good” to “excellent” aerobic capacity, suggesting a plateau in reduced relative risk. Adapted from reference #17.

Figure 2. Oxygen uptake during intermittent activity that requires 17.5 mL/kg/min (5 METs) during continuous effort is shown by the solid line. Oxygen consumption for the same activity performed intermittently (2 minutes of work [W] followed by 1 minute of rest [R]) is shown by broken line. Oxygen consumption is lower during intermittent exercise than for continuous exercise because of partial repayment of oxygen debt during interspersed rest periods.

Table 1

The conventional Bruce treadmill protocol with MET values* for each minute interval completed

				MET Requirement*		
Stage	MPH	Grade	Minutes	Men	Women	Cardiac
I	1.7	10%	1	3.2	3.1	3.6
			2	4.0	3.9	4.3
			3	4.9	4.7	4.9
II	2.5	12%	4	5.7	5.4	5.6
			5	6.6	6.2	6.2
			6	7.4	7.0	7.0
III	3.4	14%	7	8.3	8.0	7.6
			8	9.1	8.6	8.3
			9	10.0	9.4	9.0
IV	4.2	16%	10	10.7	10.1	9.7
			11	11.6	10.9	10.4
			12	12.5	11.7	11.0
V	5.0	18%	13	13.3	12.5	11.7
			14	14.1	13.2	12.3
			15	15.0	14.1	13.0

*MET values are for each minute *completed*. Note that women and cardiac patients achieve *lower* VO_2 for equivalent workload. Holding on to front rail will *increase* the apparent MET expenditure or capacity.

Adapted from reference #6.

Table 2A

Fitness and mortality in men, Aerobics Center Longitudinal Study, fitness categories*

Fitness Group	Age Groups (years) 20–29	30–39	40–49	50–59	60–69	70–79
			METs Achieved			
Poor	≤10.9	≤10.5	≤9.9	≤8.9	≤7.8	≤6.8
Average	11.0–13.0	10.6–12	10.0–12.0	9.0–10.8	7.9–9.9	6.9–8.7
Good	≥13.1	≥12.7	≥12.1	≥10.9	≥10.0	≥8.8

Table values are maximal METs attained during the exercise test

*Adapted from reference #18.

Table 2B

Fitness and mortality in women, Aerobics Center Longitudinal Study, fitness categories*

Fitness Group	Age Groups (years) 20–29	30–39	40–49	50–59	60–69	70–79
			METs Achieved			
Poor	≤9.0	≤8.5	≤8.0	≤7.3	≤6.8	≤6.1
Average	9.1–11.2	8.6–10.4	8.1–9.9	7.4–8.9	6.9–8.2	6.2–7.5
Good	≥11.3	≥10.5	≥10.0	≥9.0	≥8.3	≥7.6

Table values are maximal METs attained during the exercise test

*Adapted from reference #18.

Table 3

Variables influencing resting metabolic rate[*]

- Age
- Body composition
  – Fat mass
  – Fat-free mass
- Cardiorespiratory fitness
- Resistance training
- Clinical status
  – Coronary artery disease
  – Congestive heart failure
- Prescribed medications
  – Beta-blockers
- Gender

[*] Adapted from references 29, 35.

Table 4

Changes in heart rate to estimate energy expenditure (METs) during daily activities*

The energy cost of any activity, expressed as METs, can be estimated from the resting and exercise heart rates using the equation:

$$\boxed{\text{METs} = (6 \times \text{Heart Rate Index}) - 5}$$

where the Heart Rate Index equals the activity heart rate divided by the resting heart rate.

Example #1 A tennis player's resting heart rate of 60 beats per minute (bpm) is increased to 120 bpm during a tennis match. His MET level is estimated as follows: 120 bpm/60 bpm = 2.0 Heart Rate Index which is multiplied by 6, yielding 12, from which we subtract 5, yielding an estimated 7 METs.

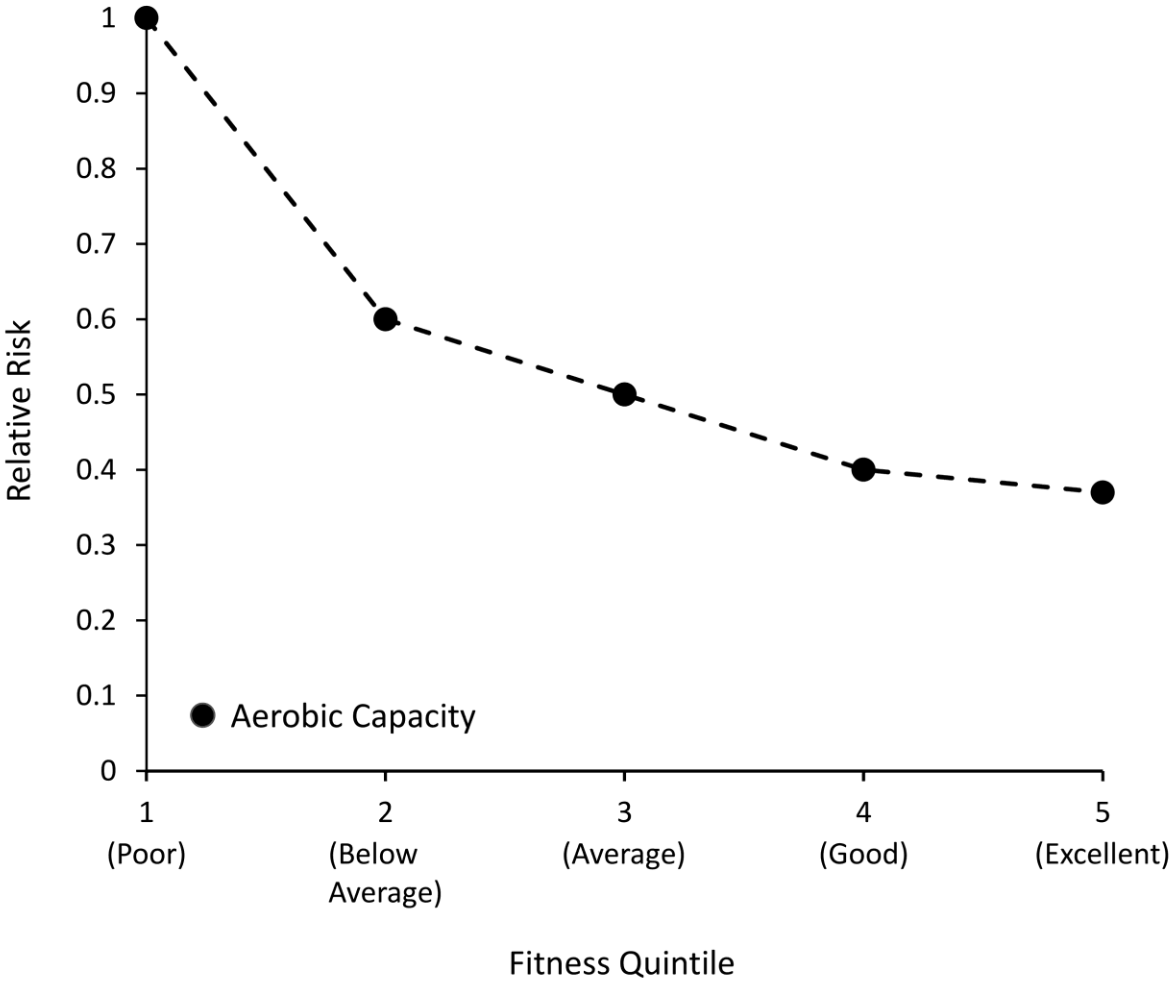
$$(120/60 \times 6) - 5 = (2 \times 6) - 5 = 7 \text{ METs}$$

Example #2 A recreational walker with a resting heart rate of 70 bpm walks at 105 bpm. Her estimated MET level is….

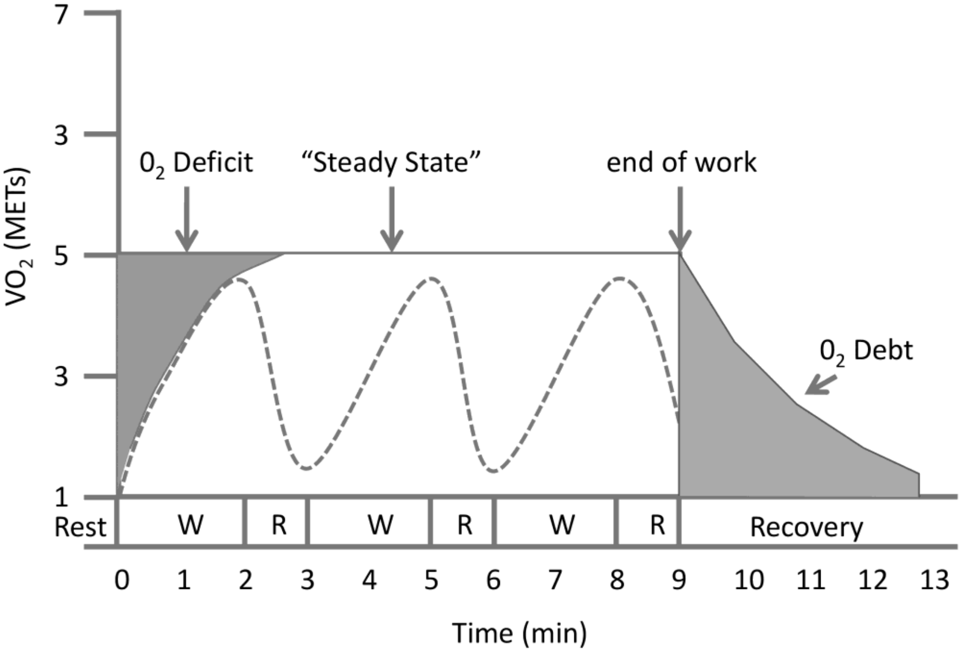
$$(105/70 \times 6) - 5 = (1.5 \times 6) - 5 = 4 \text{ METs}$$

---

*Adapted from reference #40.



Aerobic capacity_Fig 1_bestsetConverted.png



Exercise testing_Fig 2_bestsetConverted.png