

Exercise Is Medicine? The Cardiorespiratory Implications of Ultra-marathon

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Abstract

Regular physical activity decreases the risk of cardiovascular disease, type II diabetes, obesity, certain cancers, and all-cause mortality. Nevertheless, there is mounting evidence that *extreme* exercise behaviors may be detrimental to human health. This review collates several decades of literature on the physiology and pathophysiology of ultra-marathon running, with emphasis on the cardiorespiratory implications. Herein, we discuss the prevalence and clinical significance of postrace decreases in lung function and diffusing capacity, respiratory muscle fatigue, pulmonary edema, biomarkers of cardiac injury, left/right ventricular dysfunction, and chronic myocardial remodeling. The aim of this article is to inform risk stratification for ultra-marathon and to edify best practice for personnel overseeing the events (*i.e.*, race directors and medics).

Introduction

Physical activity, including structured exercise, is preventative in a myriad of lifestyle-related diseases, including cardiovascular disease (CVD), type II diabetes, obesity, certain cancers, and all-cause mortality (1–4). Guidelines from the U.S. Department for Health and Human Services, agreed upon by the American Medical Association (AMA) and the World Health Organization, are to engage in at least 150 min to 300 min (2.5 h to 5 h) of moderate-intensity aerobic physical activity per week, and to perform muscle-strengthening exercises on 2 d·wk⁻¹ or more (5). Long periods of sedentary behavior (*e.g.*, uninterrupted office work) have been independently associated with an increased risk of CVD (6). Accordingly, a focus of recent study has been workplace interventions to reduce sitting time (7).

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In 2010, approximately one-third of the world's population was classified as physically inactive (8). To combat the high prevalence of physical inactivity, and the associated health and financial burden, the AMA and the American College of Sports Medicine (ACSM) jointly established the Exercise is Medicine[®] initiative to elevate the status of physical activity in primary health care. The program called for the integration of basic physical activity and exercise prescription into the standard patient care process (9). The initiative further advocated that every patient receive an assessment for physical activity levels,

counseling, exercise prescription, and a physical activity referral (*e.g.*, to an exercise professional, physiotherapist, or wellness program). This concept characterizes exercise like a medication, with a “dose” that includes frequency, intensity, duration, and mode. As with all medicines, there is a minimum dose required to evoke a physiological benefit, an optimum range, and a maximal dose above which further benefits will not be obtained. There also is likely to be a dose above which any medication, including exercise, causes toxicity. For exercise training, the therapeutic ratio is high, but not infinite.

Indeed, paradoxical to the data concerning the harmful effects of physical inactivity, there is a growing body of work suggesting that *extreme* exercise behaviors may be detrimental to human health. The number of individuals participating in ultra-marathon has been steadily increasing for several decades (10). While an ultra-marathon is generally defined as a footrace that exceeds the marathon distance of 26.2 miles (42.2 km) (11), the actual distances contested in single-stage competition can be extreme and highly variable, requiring exercise bouts lasting between 6 h and 48 h; for example, Blackwater Trail in Florida, USA (31 miles/50 km); Comrades Marathon in Durban, South Africa (56 miles/90 km); Western States Endurance Run in California, USA (100 miles/161 km); and Spartathlon in Athens, Greece (152 miles/245 km). The distances of multistage races can range from 150 miles/240 km (Marathon Des Sables in the Sahara Desert, Africa) to 3100 miles/4989 km (Self-Transcendence 3100 in New York, USA). The combined physiological stress evoked by race distance/duration, the remote locations, varying terrain, and extremes

of temperature and altitude has the potential to evoke pathological consequences for all body systems (12). Accordingly, there may be an upper limit beyond which the risks of exercise engagement exceed the benefits. Moreover, if such an “upper limit” does exist, it is yet to be defined and remains a topic of contention among scientists and health professionals.

This review draws attention to the general physiology and pathophysiology of ultra-marathon running, with emphasis on the cardiorespiratory implications. The aim of the article is to inform risk stratification for the sport, and edify best practice for personnel overseeing the events (*i.e.*, race directors and medics).

Discussion

Physiological Characteristics of Ultra-marathon Runners

Ultra-marathon runners generally contest their first race at the age of 36 y, following ~7 y of competition in running races of shorter distance (13). Relative to marathon or half-marathon, peak performance in ultra-marathon tends to occur at an older age, and the age of peak performance increases with race distance (Table) (12). There is broad variability in the physical characteristics of ultra-marathon runners. Nevertheless, a cohort of athletes contesting 24-h races were reported as having a mean body mass of ~73 kg (14), while elite runners contesting similar distances exhibited values of ~60 kg (15). Marathon running is thought to evoke ~75% $\dot{V}O_{2max}$ and moderate to high levels of pulmonary ventilation (>80 L·min⁻¹) (16), but there is a paucity of equivalent data in ultra-marathon running. Given that ultra-marathon runners complete more miles at a slower velocity than marathon runners (17), it is reasonable to assume that ultra-marathon will generally evoke values below that reported in marathon. Maximal aerobic power and velocity at $\dot{V}O_{2max}$ still appear to be important predictive variables in ultra-marathon performance (14,18). Surveys of >1200 ultra-marathon runners show them as healthier than age-matched population norms, with rare instances of coronary heart disease (~0.7%), cancer (~4.5%), stroke (~0.7%), and diabetes (~0.7%) (19), although these data may be subject to selection bias. By contrast, allergies (~25%) and exercise-induced asthma (~13%) were reported as more prevalent in ultra-marathon runners (19). Finally, while the incidence of sudden cardiac arrest in runners is 0.54 per 100,000, it is significantly higher during marathons versus half marathons (1.01 vs 0.27 per 100,000) and higher in men versus women (0.90 vs 0.16 per 100,000) (20). There are no data to this effect specific to ultra-marathon.

Table.

The age of peak performance in ultra-marathon increases with race distance (12).

Race Duration	Mean Age (y)	95% CI (y)
6 h	33.7	32.5–34.9
12 h	39.4	38.9–39.9
24 h	43.5	43.1–43.9
48 h	46.8	46.1–47.5
72 h	43.6	40.9–46.3
6 d	44.8	43.9–45.7
10 d	44.6	42.9–46.3

Influence of Ultra-marathon on the Respiratory System

In terms of the maximal capacity for ventilation, the respiratory machinery is thought to be overbuilt for the demands of exercise. Nevertheless, there are several mechanisms that potentially limit pulmonary performance, including: airflow limitation, narrowing/obstruction of the upper-airway, exercise-induced arterial hypoxemia owing to a widened alveolar-arterial O₂ pressure difference, and respiratory muscle fatigue (21,22). In a study of 110 endurance runners, lung function (spirometry) was negatively and independently associated with marathon time (forced vital capacity [FVC]: $r = -0.41$; $P < 0.001$; forced expiratory volume in one second [FEV₁]: $r = -0.40$; $P < 0.001$; peak expiratory flow [PEF]: $r = -0.50$; $P = 0.005$) (23). While causation cannot be determined, these data offer an insight into the potential impact of lung function on endurance performance. Most commonly determined via spirometry (the ability to inspire and expire volumes of air as a function of time), the lung function response to marathon running was studied in the 1920s (24), but equivalent data in ultra-marathon were not published until several decades later. The first study to assess changes in pulmonary function in response to a 100-km footrace (Lake Waramaug Ultra in Connecticut, USA) reported significant postrace decreases in FVC, FEV₁, and PEF in the region of 10% to 15% (25). The diminished lung function was attributed, at least in part, to small airway obstruction manifesting as a postrace decrease in maximal midexpiratory flow at 50% FVC (MEF₅₀). These early data have since been replicated in footraces of longer distance, for example, 110-km (26), 330-km (27), and 24-h running (28).

The aforementioned studies report inconsistent evidence of airway obstruction (for review, see [29]); therefore, the mechanisms that underpin the acute postrace decreases in lung function are not definitively known. Using the exhaled nitric oxide technique, airway inflammation and subsequent obstruction have been observed in those without asthma following marathon running (30). Others report a greater relative increase in pulmonary prooxidative levels (hydrogen peroxide and nitrogen dioxide) following marathon running when compared with half-marathon or the 10-km distance, suggesting that running time is positively associated with the magnitude of the acute postexercise, prooxidative state (31). However, there are limited data to support this hypothesis in ultra-marathon. It also is likely that ultra-marathon evokes a degree of fatigue in the respiratory muscles, thereby reducing their force-generating capacity (see below). Despite numerous reports of pulmonary dysfunction following marathon and ultra-marathon, a recent reanalysis of the data using regression equations from the Global Lung Function Initiative (32) revealed that postrace values rarely fall below the lower-limits of normal, and that the postrace FEV₁/FVC ratio remains acceptable in all studies (range, 0.78–0.85) (29). Thus, for most individuals (at least in the published literature), the postrace decreases in lung function following ultra-marathon are unlikely to be of clinical concern. Ultra-marathon may provoke more pronounced clinical manifestations in individuals with below-average baseline function, or in those with preexisting respiratory disorders (*e.g.*, asthma).

There are other important perturbations of the pulmonary system following prolonged running that warrant consideration. For instance, exercise-induced pulmonary edema — an abnormal accumulation of extravascular lung water (EVLW)

— has been observed (via radiographic analysis) in 17% of marathon runners, although this finding did not associate with either lung function or marathon performance (33). Exposure to hypobaric hypoxia alone has been observed to evoke increased lung water in animal models (34). Accordingly, pulmonary edema could be expected to occur during long duration ultra-marathon performed at altitude, but this has only been recently investigated. In a series of studies, pulmonary function and edema were assessed in 75 ultra-marathon runners contesting 100 mile/161 km footraces at moderate to high altitude (Ultra-Trail du Mont-Blanc and the Hong Kong 100). The authors observed a mean postrace increase in the frequency of echocardiographic “comet tails” — a sign of EVLW — with decreased lung diffusing capacity and alveolar-capillary membrane conductance (35). The EVLW and gross decreases in alveolar-capillary membrane diffusion were more pronounced in a small subset of runners, suggesting that some individuals have an increased propensity for developing pulmonary edema under these conditions (35). Decreases in lung diffusing capacity also occurred congruent with reductions in right ventricular (RV) function (36). Given that RV dysfunction following ultra-marathon is more prominent when compared to left ventricular (LV) dysfunction (37), these data indicate that there may be a disproportionate hemodynamic load on the pulmonary circulation (heart and lungs) compared to that of the periphery during ultraendurance exercise (38). Moreover, it is likely that the most pronounced cardiopulmonary perturbations are mediated by the combined stimuli of exercise intensity, duration, and environmental factors (*e.g.*, exposure to cold, dry, hypobaric hypoxic air) (39,40). These data, which mechanistically link transient dysfunction of the cardiac and pulmonary systems, are now enabling a more integrative and robust interpretation of the physiology and pathophysiology of ultra-marathon.

The main respiratory concerns of long-term participation relate to a mismatch between airway caliber and increased ventilation during exercise. There also may be chronic airway inflammation (exercise-induced asthma [EIA], exercise-induced bronchoconstriction, and airway hyperresponsiveness) particularly when training and competing in cold, dry conditions (22). In a sample of >1200 ultra-marathon runners, EIA was reported in 13% (19), likely the result of chronic airway dehydration and subsequent damage and inflammation (41), although this is far lower than that observed in Olympic athletes (20%) assessed using bronchodilator and bronchoprovocation tests (42). The self-reported 11% prevalence of asthma in ultra-marathon runners (19) is similar to 8% observed in the general population (43). Larger studies with longer follow-ups are required to further elucidate the chronic respiratory consequences of participation.

Respiratory Muscle Fatigue

Another widely studied aspect of respiratory function during exercise is the behavior of the muscles of respiration, specifically the diaphragm and major abdominals, which have important roles in ventilating the lungs and in postural control. Respiratory muscle fatigue is a phenomenon whereby muscles attached to the thoracic cage exhibit a reduced force-generating capacity relative to baseline, usually following exhaustive high-intensity exercise (21). Respiratory muscle fatigue has the potential to compromise exercise ventilatory

capacity, exacerbate dyspnea, and compromise limb-locomotor blood flow via an exercise-induced metaboreflex (21).

Using mouth-pressure maneuvers as a surrogate for respiratory muscle force output, several studies report evidence of respiratory muscle fatigue following ultra-marathon (for review, see [29]). Mouth-pressure maneuvers involve maximal inspiratory/expiratory efforts against an occluded mouthpiece. The technique is noninvasive and generally reproducible, but limited in that the maneuvers are volitional, subject to athlete motivation and a practice effect. Only one study has assessed inspiratory muscle fatigue objectively (using magnetic nerve stimulation) following ultra-marathon. By inducing action potentials in the phrenic nerves (those innervating the diaphragm), Wüthrich et al. (26) provoked involuntary inspiratory muscle contractions in 16 runners following a 110-km ultra-marathon, observing a significant (19%) reduction in the postrace mouth twitch-pressure. Their data support the notion that inspiratory muscle fatigue following ultra-marathon is likely due to peripheral neuromuscular factors, as opposed to those which are centrally mediated (Fig. 1). Worthy of note is that the race of interest (The Ultra-Trail du Mont-Blanc, which begins in the French Alps) is characterized by moderate to high altitude, high elevation gain, strict qualifying standards, and necessitates runners of exceptional ability and experience. Thus, it is likely that the course induced substantial and sustained pulmonary ventilation above-and-beyond that observed in most other race types, thus predicating the observed fatigue. The clinical implications of respiratory muscle fatigue remain unclear, especially for athletic populations. Moreover, research is needed to explore the consequences for individuals who begin ultra-marathons with below-average function.

Accordingly, with extreme physical effort, the capabilities of the respiratory system may be exceeded acutely, resulting in a relative postrace dysfunction. Nevertheless, most metrics tend to recover within 24 h to 48 h, and the respiratory system appears sufficiently robust to meet the body's metabolic needs in most instances. While there may be certain training-induced maladaptations in healthy subjects, chronic structural remodeling is more apparent in the cardiovascular system.

Influence of Ultra-marathon on the Cardiovascular System

Given the durations of ultra-marathons, and the associated dependence on aerobic energy transfer, much of the literature has focused on potential implications for the cardiovascular system. Acute functional and biochemical cardiac abnormalities are common following intense endurance exercise, although their clinical significance has been debated (44). As with most endurance events, concentrations of cardiac biomarkers (*e.g.*, creatine kinase [CK]-MB, cardiac troponin I) increase following any given ultra-marathon (45–47), although observations of a training-induced increase in muscle CK-MB discount the notion that this indicates a significant degree of myocardial tissue damage (48). Higher absolute exercise intensities are generally associated with the greatest increases in troponin concentrations, and faster ultra-marathon runners tend to exhibit greater troponin concentrations relative to slower runners (49). While the appearance of myocardial biomarkers appears to be a common, transient response to ultra-marathon, more research is needed to elucidate its clinical implications, particularly in relation to ultra-marathon runners who rarely experience chronic myocardial injury.

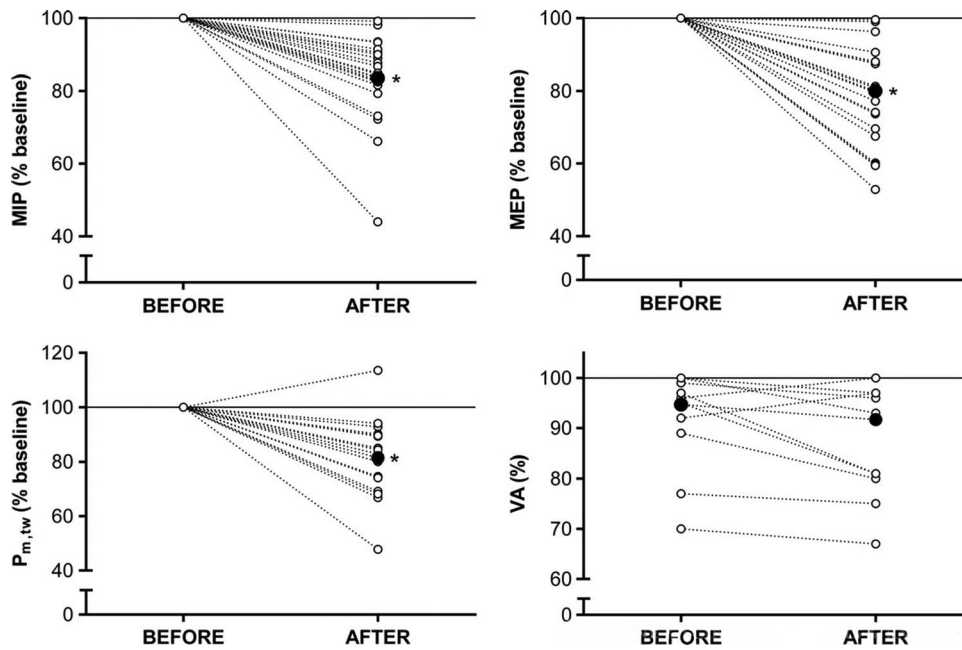


Figure 1: Prerace to postrace changes in mouth twitch-pressure ($n = 16$), volitional maximum inspiratory pressure (MIP, $n = 22$), maximum expiratory pressure (MEP, $n = 22$), and voluntary activation ($n = 16$). Open circles depict individual data and closed circles depict mean values. *Significantly different relative to prerace, $P < 0.01$. From Wüthrich et al. (26).

In terms of functional cardiac changes, ultraendurance exercise appears sufficient to acutely evoke both LV and RV dysfunction and/or fatigue. Impaired cardiac contractility and altered preload have been observed in finishers of the Hawaii Ironman Triathlon (50). Moreover, a 100-mile (161 km) ultra-marathon (Western States endurance Run in California, USA) evoked a decrease in stroke volume from $77 \text{ mL} \pm 12 \text{ mL}$ at baseline to $64 \text{ mL} \pm 13 \text{ mL}$ immediately postrace (51); values that approached the lower-limits of normal. Other studies performing transthoracic echocardiography have revealed postmarathon decreases in both LV and RV systolic/diastolic function in amateur runners, but while systolic values were transient, diastolic abnormalities persisted at 1-month follow-up (52). The mechanisms responsible for diminished postrace stroke volume are incompletely understood, but may include RV dysfunction and horizontal RV-LV interaction, enhanced vagal reactivation (53), a downregulation of cardiac β -adrenoreceptors mediated by elevated catecholamines (54), disrupted biochemical homeostasis second to elevated free fatty acids (55), and abnormal calcium reuptake owing to a decrease in sarcoplasmic reticulum calcium ATPase (56).

Despite acute postrace LV dysfunction in some athletes, the response is generally transient and benign. Endurance exercise-associated remodeling of the LV is actually thought to be a favorable adaptation to chronic training and, moreover, LV size is a predictive variable in ultra-marathon performance (57). Following ultraendurance exercise, there also is a reduction in RV ejection fraction (58) and, when compared with the left ventricle, right ventricle dysfunction may be more pronounced and less reversible (37). The notion that the magnitude of RV dysfunction may be congruent with exercise intensity and/or duration has been explored by La Gerche et al. (59). Echocardiography was performed on athletes contesting one-of-four races of varying duration: marathon

(mean duration ~ 3 h), half-Ironman Triathlon (~ 5.5 h), Alpine cycling (~ 8 h), and Ironman Triathlon (~ 11 h). While LV function was maintained across race type, there were significant postrace reductions in all metrics of RV function, including ejection fraction. Pertinently, RV stroke volume remained depressed at 1-wk follow-up and, while acute recovery appeared complete, the authors observed chronic RV structural changes and myocardial fibrosis in a small subset of athletes who exhibited the longest competition history (Fig. 2) (59).

Indeed, chronic RV remodeling is most commonly observed in highly-trained athletes who compete frequently in events of duration longer than marathon (60,61). In a study of lifelong, veteran male marathon and ultra-marathon runners undergoing cardiac magnetic resonance imaging with late gadolinium enhancement, the athletes exhibited larger absolute and indexed LV and RV end-diastolic and systolic volumes, intraventricular septum thickness during diastole, posterior wall thickness during diastole, and reduced LV and RV ejection fractions relative to age-matched controls (62). Moreover, 6 of 12 athletes presented with evidence of myocardial fibrosis detected using late gadolinium enhancement, and this was positively associated with the number of years training ($P < 0.001$), number of competitive marathons ($P < 0.001$), and ultra-marathon ($P < 0.007$) (62). Despite the small sample size, these data collectively suggest that chronic participation in ultraendurance sport may result in pathological changes in myocardial structure and function; indeed, under such conditions, it is possible that an arrhythmogenic RV cardiomyopathy-like phenotype may be acquired through intense exercise without an identifiable genetic predisposition (60).

An important consideration is whether or not chronic changes in cardiovascular structure and/or function — should they be reasonably replicated and shown in larger samples — result in an increased risk of mortality in otherwise healthy individuals,

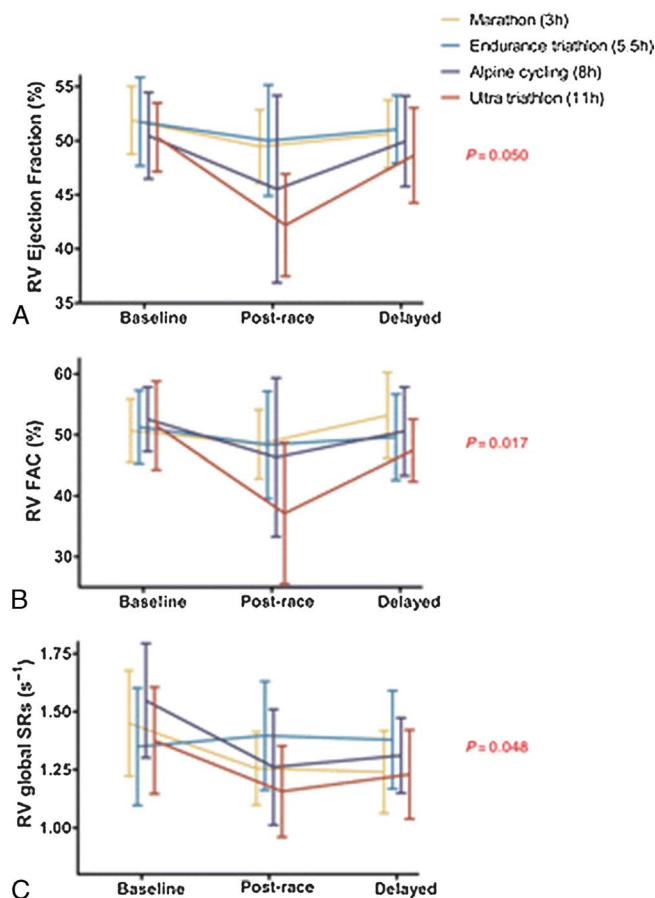


Figure 2: Duration-dependent increases in RV dysfunction. Ejection fraction (A), fractional area change (B), and systolic strain rate (C) decreased in the postrace setting. There was a significant interaction between event type and time point (P value) with greater functional declines in those completing the longest event (ultra-triathlon). From La Gerche et al. (59).

especially when considering the benefits of regular exercise in lowering CVD risk (3). Early research suggests protective effects of such training. Following nitroglycerin administration, ultra-marathon runners were found to have significantly greater coronary artery vasodilatory capacity when compared to age-matched, healthy controls, and a greater LV mass index (152 vs 116 $\text{g}\cdot\text{m}^2$) (63). Moreover, in a longitudinal study of >2,000 highly-active and healthy individuals, treadmill testing, coronary artery calcium (CAC) scanning, and a 10-y follow-up revealed that those with extraordinary levels of physical activity ($>10,000 \text{ MET}\cdot\text{min}^{-1}\cdot\text{wk}^{-1}$) exhibited no greater CAC scores, and no greater risk of mortality, when compared to those who engaged in lower levels of activity (64). Accordingly, these data question the notion that changes in cardiac morphology associated with extreme exercise behaviors represent a clinical concern, and such engagement may even bestow beneficial effects.

Worthy of consideration is that the extreme exercise behaviors studied ($\sim 35 \text{ h}\cdot\text{wk}^{-1}$ of moderate-intensity physical activity) are unlikely to evoke a similar physiological stress to that imposed by periodic participation in ultramarathon competition; *i.e.*, it may be repeated exposure to the stress of racing, rather than high-volume training, which leads to chronic

cardiovascular abnormalities. Indeed, even ultramarathon runners, who devote many hours per week to accumulating a high weekly mileage, are unlikely to replicate in training the magnitude of stress/strain encountered during competition, the latter of which may exceed 24-h in duration. As such, the demands and periodic stress of endurance *competition* may be an important independent risk factor that warrants closer study.

Additional Considerations

A full discussion of the various facets underpinning ultramarathon performance — such as hydration status, energy and electrolyte balance — is outside the scope of this manuscript (see [65] for further review). Nevertheless, further to the cardiorespiratory implications discussed, several issues deserve brief consideration owing to their substantial influence on ultramarathon success. First, ultramarathon runners must endure severe muscle damage, particularly in the course of racing. Creatine kinase concentrations following the Western States Endurance Run in California, USA (100 miles/161 km) increased from 117 U/I at baseline to 17,965 U/I (66), values which vastly exceeded healthy norms. Others have observed whole-blood markers of muscle breakdown to be higher following ultramarathons compared with marathons run at a relatively faster pace (67,68). These data suggest that race distance and/or duration may mediate muscle damage more than race intensity. Most ultramarathons are contested on undulating and/or mountainous terrain, and the magnitude of muscle damage may be attributable, at least in part, to downhill running which itself is associated with greater joint flexion angles relative to level or uphill running. This exaggerates the eccentric component of impact loading, thereby increasing muscle damage (69).

Second, a common cause of noncompletion and/or reduced performance in ultramarathon is gastrointestinal (GI) distress. A conservative estimate is that 30% to 50% of athletes experience GI-related issues during ultramarathon (70), although others report values as high as 70% to 80% (71,72). The pathophysiology of GI distress in ultra-marathon is multifactorial, but is likely attributable to reduced mesenteric blood flow and a relative GI hypoperfusion (73). This is often predicated by dehydration, ingestion of highly-concentrated carbohydrates, and/or increased core temperature (65). Learning to mitigate both muscle damage and GI distress is an important component of the periodized training and nutrition program. These factors should be considered alongside the respiratory and cardiovascular responses to racing in order to provide integrated support to the ultramarathon runner.

Implications and Future Considerations

There are a number of considerations in answering the primary question: *Is ultramarathon bad for one's health?* In short, while there are several studies in ultramarathon that have failed to observe race-induced increases in cardiac troponin (45), or 12-lead electrocardiogram abnormalities (74), these findings are in the minority. In general, ultramarathon running evokes an acute but substantial reduction in both respiratory and cardiovascular function. Postrace changes include decreases in lung function, diffusing capacity, an apparent decrease in respiratory muscle contractile force, increased potential for pulmonary edema in certain individuals, and diminished systolic/diastolic function perhaps attributable to fatigue and/or injury

to the left and right ventricles. Importantly, in most individuals and with the exception of certain metrics of RV function, these changes appear transient and likely abate within 1 wk of competition. Chronically, however, there is the potential for pathological airway remodeling (as with most endurance sports) and structural/functional cardiac abnormalities (including arrhythmias, hypertension, and myocardial fibrosis) which deserve closer scrutiny.

Subsequently, the other pertinent question is: *Are such maladaptations clinically meaningful, and do they result in an increased risk of mortality?* This question continues to be debated (44,58,74), and more data are needed to draw definitive conclusions. Until then, attention must be focused on identifying those individuals who may be at the highest risk of long-term damage. There are currently no proven screening strategies for detecting pathologic cardiovascular changes associated with extreme endurance exercise. Moreover, while use of postcompetition electrocardiogram, cardiac imaging, and assessment of cardiac biomarkers have been suggested to help identify those individuals most susceptible to negative consequences (58), this is unlikely to be financially viable on a large scale (75). Accordingly, the notion of *shared decision making* (76) is pertinent for ultra-marathon runners; when it comes to long-term participation, clinicians and athletes should work cooperatively to consider the evidence and make decisions that balance the risks/expected outcomes with patient preferences and values.

Irrespective of the aforementioned research, when ultra-marathon runners were posed the question — *If you were to learn, with absolute certainty, that ultra-marathon running was bad for your health, would you stop your ultra-marathon training and participation?* — 74% of 1349 runners responded that they would not (77). Interestingly, this group tended to exhibit higher personal goal achievement, higher ratings of psychological coping, and higher life-meaning scores on the Motivations of Marathoners Scales (77). These data suggest that the majority of runners prioritize continued participation in ultra-marathon over the potential health risks, likely compounded because, despite its popularity as a competitive sport, most ultra-marathon runners approach racing as a means of personal accomplishment (78). Ultra-marathon runners also exhibit significantly greater exercise dependence relative to marathon runners or athletes contesting races of shorter distance (79). When collated with the research showing negative physiological outcomes with long-term participation, it is likely that ultra-marathon runners may be at a greater risk of exercise-induced pathology when compared with other exercising subgroups. Finally, while the risk of such pathology is likely minimally relative to the risks associated with chronic physical inactivity, there is a middle-ground which likely maximizes the physical and psychological benefits of participation, while mitigating the possible contraindications of extreme endurance endeavors. An important, yet unexplored, question is to what extent the chronic structural/functional changes are attributable to exercise training or, instead, the cumulative stress of periodic racing.

Conclusions

The physiological, psychological, and sociological benefits of ultra-marathon running are extensive. Nevertheless, acute dysfunction of the respiratory and cardiovascular systems is highly likely following any given competition, and chronic

structural/functional abnormalities occur in a small subset of susceptible individuals. More data are needed to elucidate the clinical significance of these findings.

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