Considerations for Initiating and Progressing Running Programs in Obese Individuals

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Running has rapidly increased in popularity and elicits numerous health benefits, including weight loss. At present, no practical guidelines are available for obese persons who wish to start a running program. This article is a narrative review of the emerging evidence of the musculoskeletal factors to consider in obese patients who wish to initiate a running program and increase its intensity. Main program goals should include gradual weight loss, avoidance of injury, and enjoyment of the exercise. Pre-emptive strengthening exercises can improve the strength of the foot and ankle, hip abductor, quadriceps, and trunk to help support the joints bearing the loads before starting a running program. Depending on the presence of comorbid joint pain, nonimpact exercise or walking (on a flat surface, on an incline, and at high intensity) can be used to initiate the program. For progression to running, intensity or mileage increases should be slow and consistent to prevent musculoskeletal injury. A stepwise transition to running at a rate not exceeding 5%-10% of weekly mileage or duration is reasonable for this population. Intermittent walk-jog programs are also attractive for persons who are not able to sustain running for a long period. Musculoskeletal pain should neither carry over to the next day nor be increased the day after exercising. Rest days in between running sessions may help prevent overuse injury. Patients who have undergone bariatric surgery and are now lean can also run, but special foci such as hydration and energy replacement must be considered. In summary, obese persons can run for exercise, provided they follow conservative transitions and progression, schedule rest days, and heed onset of pain symptoms.

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INTRODUCTION

Running has rapidly increased in popularity [1] and is a highly attractive training option for attaining health and fitness. The widespread appeal of running may be due to easy access, low cost, positive feelings of accomplishment, and improvement and maintenance of overall health. Among persons who are overweight and obese, running exercise has the potential to confer multiple benefits, including a positive mental well-being, self-esteem, significant loss of adipose tissue, increased metabolic efficiency of skeletal muscle, reduction of circulating inflammatory molecules, and reduction of cardiovascular and metabolic disease risk [2].

Regular running multiple times a week is important for persons with excessive weight, because the exercise stimulus may reduce the risk for inherited obesity [3] and prevent additional weight gain over the long term [4]. Compared with walking, greater-intensity jogging or running reduces the odds ratio of weight regain after intentional weight loss [5]. Even light jogging can reduce visceral fat and body weight, thereby reducing the significant health risks posed by abdominal obesity [6]. Popular media have made running attractive and accessible to the community through Web sites, downloadable applications, and related products that personalize running plans. Numerous factors need to be considered to ensure a safe transition from inactivity to long-term participation in running. However, guidelines for safely initiating a running program and increasing its intensity for the obese population are not yet available.

Despite the recent surge of running-related scientific literature, running exercise is not typically a primary training component for obese persons. Obesity places a considerable physical burden on the musculoskeletal (MSK) system, especially on weight-bearing joints

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(ie, the low back, hips, knees, and ankles). On the basis of body mass index (BMI) values, individuals are classified as nonobese (BMI <25 kg/m^2), overweight (BMI 25-29.9 kg/m^2), or obese (BMI 30 kg/m^2). Persons with BMI values exceeding 30 kg/m^2 have a greater risk of the development of MSK degenerative joint disease such as osteoarthritis [7]. Obesity is a strong contributor to systemic inflammation, joint pain and degeneration, and subsequent comorbid joint diseases. Carrying excessive weight during exercise requires substantial effort, and this effort decreases enjoyment and personal fulfillment from participating in exercise. It is not surprising that discomfort experienced during physical activity may lead to low self-esteem and self-efficacy and create aversion to continued long-term participation. Fortunately, new evidence suggests that when obese persons exercise, the activity does not increase the risk of the development of osteoarthritis over the long term [7]. Health care professionals therefore face the challenge of balancing the patient's desire to run with the risk of developing weight-related, acute MSK injury during training.

The American College of Sports Medicine provides an excellent set of evidence-based recommendations for physical activity necessary for significant weight loss and maintenance [8]. These recommendations focus on achievement of caloric expenditure and exercise volume. The American Dietetic Association [9], The American Heart Association [10], and other organizations have carefully developed recommendations for active living and weight loss, with the primary goals of reducing comorbid metabolic disease risk. Substantial improvements in the cardiometabolic profile occur with regular running, but discussion of these cardiometabolic metrics are outside the scope of this review. Persons who are obese and have related metabolic risks should obtain medical clearance before they begin a running program. Maintenance of MSK health is also of primary importance as obese persons progress from a sedentary lifestyle to running. Yet relatively little information has been published on the MSK considerations in the transition to running, particularly the biomechanical factors, joint pain, and other elements that can influence long-term success. This article provides a narrative review of the relevant evidence and focuses on MSK issues to consider when developing running programs for obese persons.

LITERATURE SEARCH

Few studies of running in the obese population have been conducted. For this review, the literature search focused on the terms "overweight," "obese," "obesity," or "body mass index" and "joint" and "biomechanics." To capture evidence of running-related activities on MSK health, the search included the terms "running" and "exercise." To supplement the information necessary to construct considerations for running program development, terms that related to high-volume physical activity were also included, such as "military" and "military recruits." Additional searching was performed to find evidence of the relationships of high BMI and body weight on biomechanics of movement and injury onset.

RISK OF MSK INJURY

In general, safe exercise includes low-impact stationary cycling, walking, or swimming modalities [8]. Starting a running program without a transition is discouraged. Obesity is strongly related with chronic low back and lower extremity joint pain symptoms, especially with aging [11], but pain also can develop with rapid-onset, high-volume, unaccustomed exercise. Evidence in military recruits who experience an abrupt and dramatic increase in exercise (2-4 hours daily with ~7 hours weekly of marching and 4 hours of running) shows that the risk for MSK injury is high in untrained, overweight persons compared with fitter, lighter counterparts [12]. A total of 65% and 35% of these injuries were classified as overtraining and acute, respectively. The onset of pain can elicit fear avoidance behaviors and impede progress with running programs. Even with walking programs for weight loss in persons with BMIs ranging from 25-40 kg/m^2, 32% of participants reported MSK complaints that were most evident in the lower body and back [13]. High BMI values were associated with an increased risk for MSK injury and an earlier onset of injury relative to lower BMI values [13]. In novice runners preparing for their first 6.7-km running event, BMI increased the hazard ratio of MSK injury to 1.15, especially in men [14]; the average training duration in preparation for this event was approximately 383 minutes (over 8-13 weeks, 3×/wk). The Aerobics Center Longitudinal Study found that an increased volume of running (after adjusting for BMI, age, and previous injury) relative to walking exercise was related to a greater risk of MSK injury [15]. Hence a gradual transition into running from other low-impact aerobic activity would likely minimize the risk for MSK injury.

GOALS

Patient goals may not match safe training protocol. An increasing number of overweight and obese persons want to start running with the intent of completing competitive races or events ranging from 5 km to the marathon distance, mud races, and warrior runs within the next few weeks or months. These goals are not realistic. Common characteristics of overweight persons who are interested in starting to run include postpartum, retired military, or middle-aged persons wanting a lifestyle overhaul and change in appearance. These persons generally do not understand how to prepare or how much to prepare before a competitive event. As a result, MSK discomfort may set in rapidly after training is initiated. Proper guidance toward realistic goals and programs is es-

sential to prevent MSK injury and ensure long-term success with a running lifestyle.

The main goals should be gradual weight loss, avoidance of injury, and enjoyment of training. Gradual weight loss is accomplished by increasing caloric expenditure and increasing the fat oxidation rate. The risk of overuse injury on weight-bearing joints during the early stages of the running program is high, and thus prevention of MSK injury is a critical goal. Goals of distance or speed should be of secondary concern until the individual is able to accomplish a given duration of exercise. The positive health effects of weight loss and the joy of exercise itself should be the foci, rather than the magnitude of weight loss [16] during training.

INITIATING A RUNNING PROGRAM

Sedentary, obese persons face the dual challenge of carrying excessive weight and increasing the loading on the joints while starting a running program. Because an optimal method of starting a running program has not yet been identified for this population, effective and conservative approaches may be applied. For return-to-run programs involving persons with stress fractures, for example, a stepped approach of walking and running intervals that gradually shift toward longer durations of running is used; this approach may also work well for obese persons. Alternatively, a walk-jog approach that uses intervals of running at higher speeds with recuperative bouts of walking in between may be attractive, because the distance may be covered in a similar time as sustained, slower speed running. Irrespective of the targeted style of running program, the safe progression into regular running begins with regular walking. Available evidence relating to walking and the various running approaches is described next.

INITIAL WALKING PHASE

Obese persons demonstrate greater rates of oxygen use and caloric expenditure for treadmill activity across a range of speeds [17]. Supporting increasingly higher body weights during balanced, load-bearing exercise requires increasingly more oxygen consumption [17] and muscular effort and a higher metabolic rate [18]. During treadmill running, low training states, high body mass, and body fat are all related to increased caloric expenditure [19]. Obese persons ($\geq$35 kg/m^2) demonstrate increased caloric expenditure during running at speeds of 7-9 km/h compared with nonobese counterparts [20]. During the exercise, the external work of moving excess body mass is increased relative to healthy body mass by 48% [20]. Some weight loss before running long distances would therefore reduce effort perceptions and decrease the relative work for a given speed. Brisk walking is a recommended exercise for weight loss [8] and is a good transition step to continuous running. However, awareness of joint forces produced during this activity is important. A strong relationship exists between the speed of walking and the loading on the lower extremity [21]. Net muscle moments, joint loading rates, and the joint reaction forces are used to estimate this loading. Mediolateral knee joint loading patterns can be represented by the internal extension and the knee external adduction moment while walking on a level surface. Shortening the stride length during this initial walking phase increases turnover and muscle work and may enhance burning of calories [22]. Shortening stride lengths by $\sim$15% increased the metabolic cost of walking by approximately 4.6% and lowered the knee adduction angular impulse, both of which may work in concert to reduce fat stores and prevent exposure to repeated high torques during walking [23].

INCLINE WALKING

An alternate form of walking is treadmill incline training. Novice exercisers may use this approach if they are unable to walk briskly or if they have joint pain. When walking at slower speeds and on moderate inclines, moderately obese adults with a mean body mass index value of 33.4 kg/m^2 lowered the net muscle moments about the joints of the lower extremity [21]. A variety of walking speeds ranging from 0.50-1.75 m/s were used in conjunction with various treadmill incline levels ranging from 0°-9° to create different walking stimuli. In the trials with the fastest speed and lowest inclines, the ground reaction forces were greatest. The average peak knee flexion and ankle dorsiflexion angles were elevated at greater inclines. Average peak knee extension and knee adduction moments were lowered up to 26% with elevations in treadmill incline and reduced walking speed. The energy cost of inclined walking exercise was found to be similar for persons walking at slower speeds ($<$0.75 m/s) and persons walking on treadmill inclines of 6°-9° while minimizing joint loading and loading rate across lower extremity joints [21]. When obese persons walk at inclines $>$6°, balance becomes challenging, and anterior tibial discomfort may develop as these muscles are challenged. To minimize the risk of chronic tibial pain onset, the grade should be progressed by no more than 1° every 2 weeks, and the grade should not exceed 6°.

These data suggest that initiation of a running program for an obese person may include low to moderate incline walking at slower speeds to boost caloric expenditure and facilitate fat loss. Low-speed walking on an incline may help minimize lower extremity joint loading or redistribute mechanical stress loads across the load-bearing joints. This strategy may promote caloric expenditure with weight loss while preventing joint injury. An expectation is that with a $\sim$10% reduction in body weight, walking is easier [16], which will facilitate the transition to running. Persons should choose the type of walking they find most enjoyable to help promote compliance in the early stages of the program.

WALK-TO-RUN TRANSITION WALKING SPEED

If the individual is young, otherwise healthy, has no joint pain, and is willing to perform more aggressive exercise, other training options may exist. Walking at the "walk-to-run transition speed" (ie, the speed at which the person feels that he or she may prefer to start jogging) combined with dietary restrictions may help provide a high metabolic stimulus with less impact than running [24]. The walk-to-run transition speed can be found by having a person walk on a treadmill at increasing speeds until a threshold is reached at which running is more comfortable. After repeating this procedure several times to ensure that the proper speed is found, this training speed can be the one used during exercise sessions. Starting with session durations from 30 minutes and working up to 60 minutes at this speed (3×/wk) is associated with ~9% body weight loss and ~6.3% fat loss during a 6-month period [24]. A potential concern is that this exercise modality challenges the anterior tibial muscles and may feel uncomfortable. To reduce overuse injury in this muscle group with this type of fast walking and to maintain enjoyment of the activity [24], permit the patient to have at least 1 day of rest between sessions and moderate the number of consecutive days of exercise [1].

If joint pain or severe obesity precludes jogging, alternative approaches of cycle training coupled with dietary modification (eg, caloric restriction of 1200-1500 kcal for women and men [25]) over a period of 3-6 months may facilitate cardiorespiratory fitness and weight loss before the person starts jogging or running. In the cases of severe obesity with or without joint pain, a 3- to 4-year plan is realistic to safely move to a continuous running lifestyle with lower risk for MSK injury.

TRANSITION TO CONTINUOUS RUNNING

Two considerations for using the "transition to continuous running" approach are the high metabolic cost of movement and the forces acting at the lower extremity joints when obese people run. First, walking and jogging has a higher metabolic cost in obese persons compared with nonobese persons. To complete a 1.609-km distance, obese persons expend 356 kJ while walking and 490 kJ while jogging compared with nonobese persons, who expend 280 kJ while walking and 393 kJ while jogging [26]. Hence performing a given workload will feel harder metabolically for an obese person than for a nonobese person.

Second, irrespective of adiposity distribution, excessive body weight increases knee adduction moments and medial knee joint loading [27]. In our laboratory, we tested the ground reaction forces during running with simulated obesity (ie, carrying an excess 40% body weight in the abdominal region with a backwards-strapped backpack). The ground reaction force increases in direct proportion to body weight. Compared with the normal body weight condition, we found that the added weight increased the ground reaction forces during the initial impact peak by 32.8% (1706 N for simulated obesity versus 1284 N for normal body weight). A natural strategy for obese persons is to move more slowly to offset biomechanical stresses and net muscle moments at the knee [23]. Therefore the focus on the initial stages and progression of running should not be on speed but on caloric expenditure. As an obese person begins training in the first stage, the increased caloric expenditure during activity will likely contribute to a faster initial rate of weight loss compared with the later stages as body weight decreases and plateaus. Weight loss will make exercise feel easier and facilitate the transition to continual running.

To prevent MSK injury, major or rapid increases in running intensity or mileage should be avoided [1]. A stepwise transition to running at a rate not exceeding 10% increase in duration or mileage per week is sensible for the general runner. Slower progression rates between 5% and 10% of weekly mileage or duration may feel better to the obese individual. The rationale for this threshold is that this gradual exposure to increased training load with days of rest in between would permit bone tissues to "rest" and avoid mechanical failure. The lower extremity limb segments funnel forces and weight stress downward through the tibia into the foot. The anteroposterior diameter of the tibia in part dictates the tolerance of the bone to stresses placed upon it; the tibial anteroposterior diameter decreases to its narrowest point in the distal third of its length and is a vulnerable location for stress reactions and fracture with overuse. The bones of the foot are designed to absorb the impact of loading during normal activity, and they can adjust to increased loading if provided with adequate rest. In obese persons, excessive body weight is funneled through bony structures and foot contact surface that are similar in size to those in a person with a healthy body weight. A heavy person who runs, therefore, generates a very high loading on the lower extremity bones and foot platform that precedes stress injuries. This principal of obesity-related overload can be applied to the bones of any load-bearing segment, including the vertebrae, the sacroiliac joint, and the hip.

The soft tissues that support bony structures, including ligaments, tendons, cartilage, and fascia, are also exposed to obesity-related mechanical stress [28]. Data from highly trained runners show that cytokine levels increase immediately after exercise, for hours afterwards [29-31]. Immune cells infiltrate muscle tissue 24-72 hours after exercise [32] and dissipate during the following days. Because obesity is a state of chronic inflammation [33], more active rest between running sessions might be needed initially to permit tissue repair.

INTERMITTENT WALK/JOG/RUN PROGRAMS

For obese persons, continuous intense running exercise can be difficult to sustain for extended periods. Intense, intermittent walk-run exercise is more easily endured and may be a helpful approach for body weight control [34]. Compared with lower intensity exercise, high-intensity exercise increases maximal rate of oxygen consumption (VO_{2max}) to a greater extent. As training adaptations occur, the individual will be able to work at a greater percent of the VO_{2max} and burn more calories compared with a person exercising at the same relative percent of VO_{2max} [34]. Emerging evidence supports the notion that intermittent high-intensity exercise may be more effective and economical for weight and fat loss compared with sustained exercise [35].

The authors of one study compared fitness and weight loss effects of 2 different treadmill training programs for middle-aged men and women with the metabolic syndrome [36]. Women trained on a treadmill (3×/wk for 16 weeks); one group performed 4-minute intervals of running uphill at 90% of HR_{max} followed by 3 minutes of rest for a total of 40 minutes, and the comparative group exercised 47 minutes at 70% HR_{max}. After the intervention, both groups lost similar body weight, but aerobic capacity improved more in the group that trained at a higher intensity [36]. Only one MSK injury occurred, but this injury was sustained by a person in the control group. This exercise was well tolerated by the participants.

An important caution for older adults is that the walk-jog approach may be related to a risk for MSK injury compared with younger counterparts. In adults aged 70-79 years, walk-jog training at moderately high intensities (85% of heart rate reserve) for 12 weeks resulted in MSK injuries in 8 of 14 subjects (57%), compared with injuries in 1 of 21 subjects among peers who walked during this intervention period [37]. It can be reasoned that the addition of excessive weight may amplify injuries with this type of program in the older population.

MSK PAIN

Irrespective of the program or program progression, participants can use onset of pain or symptoms as guides for participation in running. Injury prevention and enjoyment are paramount to success, and pain adversely affects these factors. Muscle soreness is expected in sedentary individuals or with a big change in running duration or decline grade. Pain that increases during a walking or running session should be avoided, and when pain increases, the activity should be reduced or stopped. Joint pain should not persist or increase by 24 hours after exercise, which is an indication that the MSK system was not prepared for the running volume. In the initial phase of a running program, exercising on nonconsecutive days will permit the individual to make a self-assessment of his or her response. If an obese person with pre-existing mild joint pain initiates running (<3 points out of a 10-point scale), similar guidelines apply: the pain should not worsen during the exercise session or last into the next day. If the pain causes a limp or a compensatory gait change, the exercise volume must be reduced or the exercise must stop until a normal gait pattern is achieved.

OTHER CONSIDERATIONS

Obesity is related to relative muscle strength deficits in the lower extremity and lumbar area [28,38,39]. Syed and Davis [40] postulated that strength deficits can lead to premature muscle fatigue of the quadriceps muscle group during locomotion. As muscles fatigue, compensatory strategies in gait patterns may occur, leading to imbalance or aberrant joint loading, both of which can predispose the runner to injury. Because obesity, even in athletic persons, decreases postural control and balance [41], competing in off-road running trails, warrior runs, or mud runs is not advised for the obese novice runner. Obese persons rely on ankle plantar flexion to a greater degree than knee or hip flexion or extension during locomotion [42]. The wobbling mass center in an active obese individual challenges balance control and may contribute to instability on uneven surfaces. Once weight loss occurs and muscle strength is improved, the participant can better tolerate contact surface perturbations in the field. Strength training exercise before starting a running program and during the program may help maintain movement control. Some key exercises are shown in Table 1.

A COMMENT ON THE "FORMERLY OBESE" CONTINGENT

A growing population of patients who have undergone bariatric surgery is interested in pursuing running to achieve fitness, maintain body weight, and develop self-esteem. However, postoperative exercise or running guidelines have not yet been established. The typical time line for the patient to establish new eating habits alone may take 1-2 years. Because energy intake is severely limited in this group after surgery, exercise endurance declines and fatigue occurs quickly. A sensible approach is for the patient to work with a sports dietician to determine the appropriate rehydration and caloric replacement schedule that minimizes fatigue and spares glycogen and protein during training or races. Caloric needs of an exerciser may be compromised at the expense of hydration [43]. Caution is required when one consumes carbohydrates to prevent the "dumping syndrome" (ie, cold sweats and diarrhea).

If the running program feels too difficult to maintain, a slower speed and/or shorter duration may be required to shift fuel use toward a higher fat content. Many patients who have undergone bariatric surgery prefer less vigorous activity such

Table 1. *Proposed strengthening exercises for preparing an obese person for a running program*

Exercise	Purpose
Feet	Increases strength of foot muscles to improve maintenance of arch during contact phase
Pick up small objects from the floor with the toes and place into a cup	
Standing balance with one leg on the floor and the other leg up like a flamingo	
Move to a soft surface, like a foam mat, and repeat	
Ankles	Increases ankle stability and strength and decreases risk of arch drop or collapse during the contact phase
Heel raise (perform with a single leg to maximize benefit; stand on a stair)	
Toe raise (perform with a single leg to maximize benefit)	
Use a wobble board (with a wall available for support)	
Range of motion (create widest circle with the toes)	
Bent knee wall stretch	Increases hip abductor strength and reduces the risk of knee drop and arch drop during the gait cycle; develops gluteal and hip abductor strength and control of knee flexion
Hip abductors	
Lying hip abduction: initially start with the leg alone and then progress to use of a resistance band	
Standing hip abduction: initially start with the leg alone; can progress to use of a resistance band	
Standing sideways on a stair, drop one foot to the floor and keep the supporting knee moving over the second toe	
Quadriceps	Increases knee extension strength to support weight at the foot strike and contact phase
Wall squats or standing squats: initially start with the leg alone; can progress to use of hand-held weights	
Lunge; start by focusing on good form, even if the degree of knee flexion is small; progress to deeper lunges over weeks and months	
Lower back and abdomen	Increases lumbar strength and abdominal strength to help prevent pelvis excessive forward tilt during running
Back extensions while lying on the ground	
While on the hands and knees, extend one leg out at a time and keep the spine straight; alternate leg extensions	
Practice throughout the day: contract the abdominal muscles and tuck in the pelvis; repeat several times	

as brisk walking (80% of a group preferred brisk walking compared with 16% who preferred jogging/running) [44]. Potentially, this group may enjoy the walk-jog approach described previously rather than the sustained running approach. This contingent may have difficulty performing endurance events longer than a 10-km run. Running a 5- to 10-km event with either a continual run or a walk-jog approach may be adequate for sustaining weight loss and enjoyment of activity. Whether exercise tolerance or performance increases, decreases, or levels off over time in this population has yet to be determined. Further research is required in this clinical population.

SUMMARY

Obese persons can achieve a running lifestyle when initiation and progression occurs conservatively over a period of months or years, depending on the goals. Preemptive strengthening may facilitate the transition to running while preventing MSK injury. Selection of a program of either continuous running or a walk-run/jog program can be based on preference and level of enjoyment, as long as the program does not induce lingering MSK discomfort or pain. The long-term goals of the running program should include fat loss, injury prevention, and maintaining the enthusiasm of running. Rest time between running sessions is vital for bony and soft-tissue repair and adaptation.

REFERENCES

1. Fredericson M, Misra AK. Epidemiology and aetiology of marathon running injuries. Sports Med 2007;37:437-439.
2. Shipway R, Holloway I. Running free: Embracing a healthy lifestyle through distance running. Perspect Public Health 2012;130:270-276.
3. Williams PT. Attenuating effect of vigorous activity on the risk for inherited obesity: A study of 47,691 runners. PLoS One 2012;7: e31436.
4. Williams PT. Maintaining vigorous activity attenuates 7-yr weight gain in 8340 runners. Med Sci Sports Exerc 2007;39:801-809.
5. Mekary RA, Feskanich D, Hu FB, Willett WC, Field AE. Physical activity in relation to long-term weight maintenance after intentional weight loss in premopausal women. Obesity (Silver Spring) 2010;18: 167-174.
6. Ohkawara K, Tanaka S, Miyachi M, Ishikawa-Takata K, Tabata I. A dose-response relation between aerobic exercise and visceral fat reduction: Systematic review of clinical trials. Int J Obes (Lond) 2007;32:395.
7. Mork PJ, Holtermann A, Nilsen TI. Effect of body mass index and physical exercise on risk of knee and hip osteoarthritis: Longitudinal

data from the Norwegain HUNT study. J Epidemiol Community Health 2012;66:678-683.
8. Donnelly JE, Blair SN, Jakicic JM, et al. American College of Sports Medicine Position Stand. Appropriate physical activity intervention strategies for weight loss and prevention of weight regain for adults. Med Sci Sports Exerc 2009;41:459-471.
9. Seagle HM, Strain GW, Makris A, Reeves RS, Association. AD. Position of the American Dietetic Association: Weight management. J Am Diet Assoc 2009;109:330-346.
10. Rao G, Burke LE, Spring BJ, et al. New and emerging weight management strategies for busy ambulatory settings: A scientific statement from the American Heart Association endorsed by the Society of Behavioral Medicine. Circulation 2011;124:1182-1203.
11. Vincent HK, Vincent KR, Seay AN, Hurley RW. Functional impairment in obesity: A focus on knee and back pain. Pain Med 2011;1:427-439.
12. Rosendal L, Langberg H, Skov-Jensen A, Kjaer M. Incidence of injury and physical performance adaptations during military training. Clin J Sports Med 2003;13:2003.
13. Janney CA, Jakicic JM. The influence of exercise and BMI on injuries and illnesses in overweight and obese individuals: A randomized control trial. Int J Behav Nutr Phys Activity 2010;6:1.
14. Buist I, Bredeweg SW, Lemmink KA, van Mechelen W, Diercks RL. Predictors of running-related injuries in novice runners enrolled in a systematic training program: A prospective cohort study. Am J Sports Med 2010;38:273-280.
15. Colbert LH, Hootman JM, Macera CA. Physical activity-related injuries in walkers and runners in the aerobics center longitudinal study. Clin J Sports Med 2000;10:259-263.
16. Larsson UE, Mattsson E. Influence of weight loss programmes on walking speed and relative oxygen cost (%VO2max) in obese women during walking. J Rehabil Med 2003;35:91-97.
17. Lafortuna CL, Agosti F, Galli R, Busti C, Lazzer S, Sartorio A. The energetic and cardiovascular response to treadmill walking and cycle ergometer exercise in obese women. Eur J Appl Physiol 2008;103:707-717.
18. Peyrot N, Thivel D, Isacco L, Morin JB, Belli A, Duche P. Why does walking economy improve after weight loss in obese adolescents? Med Sci Sports Exerc 2012;44:659-665.
19. Bunc V. Energy cost of treadmill running in non-trained females differing in body fat. J Sports Med Phys Fitness 2000;40:290-296.
20. Taboga P, Lazzer S, Fessehatsion R, Agosti F, Sartorio A, di Prampero PE. Energetics and mechanics of running men: The influence of body mass. Eur J Appl Physiol 2012;112:4027-4033.
21. Ehlen KA, Reiser RFn, Browning RC. Energetics and biomechanics of inclined treadmill walking in obese adults. Med Sci Sports Exerc 2011;43:1251-1259.
22. Russell EM, Braun B, Hamill J. Does stride length influence metabolic cost and biomechanical risk factors for knee osteoarthritis in obese women? Clin Biomech (Bristol, Avon) 2010;25:438-443.
23. Browning RC, Kram R. Effects of obesity on the biomechanics of walking at different speeds. Med Sci Sports Exerc 2007;39:1632-1641.
24. Beltaifa L, Chaouachi A, Zerifi R, et al. Walk-run transition speed training as an efficient exercise adjunct to dietary restriction in the management of obesity: A prospective intervention pilot study. Obes Facts 2011;4:45-52.
25. Diabetes Prevention Program (DPP) Research Group. The Diabetes Prevention Program (DPP): Description of lifestyle intervention. Diabetes Care 2002;25:2165-2171.
26. LeCheminant JD, Heden T, Smith J, Covington NK. Comparison of energy expenditure, economy, and pedometer counts between normal weight and overweight or obese women during a walking and jogging activity. Eur J Appl Physiol 2009;106:675-682.
27. Segal NA, Yack HJ, Khole P. Weight, rather than obesity distribution, explains peak external knee adduction moment during level gait. Am J Phys Med Rehabil 2009;88:180-188.
28. Wearing SC, Hennig EM, Byrne NM, Steele JR, Hills AP. Musculoskeletal disorders associated with obesity: A biomechanical perspective. Obes Rev 2006;7:239-250.
29. Nieman DC, Henson DA, Smith LL, et al. Cytokine changes after a marathon race. J Appl Physiol 2001;91:109-114.
30. Santos VC, Levada-Pires AC, Alves SR, Pithon-Curi TC, Curi R, Cury-Boaventura MF. Changes in lymphocyte and neutrophil function induced by a marathon race. Cell Biochem Function 2012, doi: 10.1002/cbf.2877 [Epub ahead of print].
31. Scherr J, Braun S, Schuster T, et al. 72-h kinetics of high-sensitive troponin T and inflammatory markers after marathon. Med Sci Sports Exerc 2011;43:1819-1827.
32. Smith LL. Cytokine hypothesis of overtraining: A physiological adaptation to excessive stress? Med Sci Sports Exerc 2000;32:317-331.
33. Gregor MF, Hotamisligil GS. Inflammatory mechanisms in obesity. Ann Rev Immunol 2011;29:415-445.
34. Hunter GR, Weinsier RL, Bamman MM, Larson DE. A role for high intensity exercise on energy balance and weight control. Int J Obes Rel Metab Disord 1998;22:489-493.
35. Boutcher SH. High-intensity intermittent exercise and fat loss. J Obes 2011;2011:868305.
36. Tjønna AE, Lee SJ, Rognmo Ø, et al. Aerobic interval training versus continuous moderate exercise as a treatment for the metabolic syndrome: A pilot study. Circulation 2008;118:346-354.
37. Pollock ML, Carroll JF, Graves JE, et al. Injuries and adherence to walk/jog and resistance training programs in the elderly. Med Sci Sports Exerc 1991;23:1194-1200.
38. Capodaglio P, Vismara L, Menegoni F, Baccalaro G, Galli M, Grugni G. Strength characterization of knee flexor and extensor muscles in Prader-Willi and obese patients. BMC Musculoskelet Disord 2009;10:47.
39. Vincent KR, Braith RW, Vincent HK. Influence of resistance exercise on lumbar strength in older, overweight adults. Arch Phys Med Rehabil 2006;87:383-389.
40. Syed IY, Davis BL. Obesity and osteoarthritis of the knee: Hypotheses concerning the relationship between ground reaction forces and quadriceps fatigue in long-duration walking. Med Hypotheses 2000;54:182-185.
41. Handrigan GA, Berrigan F, Hue O, et al. The effects of muscle strength on center of pressure-based measures of postural sway in obese and heavy athletic individuals. Gait Posture 2012;35:88-91.
42. DeVita P, Hortobágyi T. Obesity is not associated with increased knee joint torque and power during level walking. J Biomech 2003;36:1355-1362.
43. Clark N. Case study: Nutrition challenges of a marathon runner with a gastric bypass. Int J Sport Nutr Exerc Metab 2011;21:515-519.
44. Akkary E, Cramer T, Chaar O, et al. Survey of the effective exercise habits of the formerly obese. J Soc Laparoendosc Surg 2010;14:106-114.