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Nutritional Recommendations for Synchronized Swimming

Sherry Robertson, Dan Benardot, and Margo Mountjoy

The sport of synchronized swimming is unique, because it combines speed, power, and endurance with precise synchronized movements and high-risk acrobatic maneuvers. Athletes must train and compete while spending a great amount of time underwater, upside down, and without the luxury of easily available oxygen. This review assesses the scientific evidence with respect to the physiological demands, energy expenditure, and body composition in these athletes. The role of appropriate energy requirements and guidelines for carbohydrate, protein, fat, and micronutrients for elite synchronized swimmers are reviewed. Because of the aesthetic nature of the sport, which prioritizes leanness, the risks of energy and macronutrient deficiencies are of significant concern. Relative Energy Deficiency in Sport and disordered eating/eating disorders are also of concern for these female athletes. An approach to the healthy management of body composition in synchronized swimming is outlined. Synchronized swimmers should be encouraged to consume a well-balanced diet with sufficient energy to meet demands and to time the intake of carbohydrate, protein, and fat to optimize performance and body composition. Micronutrients of concern for this female athlete population include iron, calcium, and vitamin D. This article reviews the physiological demands of synchronized swimming and makes nutritional recommendations for recovery, training, and competition to help optimize athletic performance and to reduce risks for weight-related medical issues that are of particular concern for elite synchronized swimmers.

Keywords: synchronized swimmer, nutrition, female athletes, aesthetic sport

Synchronized swimming is unique among aquatic sports, requiring a mixture of endurance, power, agility, acrobatics, and flexibility, which must be combined to produce an artistic performance. The athletes must also precisely synchronize their movements with one or more teammates and the music. Producing the desired performance outcome requires that synchronized swimmers train for long hours in a variety of exercise modalities (Mountjoy, 2009).

The 1984 Olympic Games was the inaugural Olympiad for the solo and duet events of synchronized swimming, and the team event was added at the 1996 Olympic program. In addition, synchronized swimmers also compete at Continental and World Championships. Fédération Internationale de Natation (FINA; the international governing body for aquatic sports) governs the rules of synchronized swimming. The FINA program includes the solo, duet, team (8 athletes), and combination events (up to 10 athletes); the last of these is a 5-min routine incorporating solo, duet, and team into one performance. Solo, duet, and team events consist of both technical and free competitions. The technical competition has 6–10 mandatory required elements in a predetermined order that illustrate various skills, such as flexibility, power, strength, and precision. The free competition is longer in duration and has no required elements, thus allowing for freedom of expression and music interpretation (Fédération Internationale de Natation, 2013).

Much like gymnastics and figure skating, synchronized swimming has a complex judging system that evaluates many components of skill, synchronization, and artistic impression. Body shape is not a judged element, but appearance and body composition are a prime focus for coaches and athletes. Coupled with the intense training demands and the aesthetic nature of the sport, the nutritional demands of the synchronized swimmer are also complex (Mountjoy, 1999). This article is a review of the existing sport science literature on nutrition in synchronized swimming. Specific nutritional recommendations are presented along with the identification of research gaps, which have become evident after an intensive literature review.

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Training and Competition Demands of Synchronized Swimming

Synchronized swimming demands a combination of complex technical skills and a high level of fitness that incorporates power, speed, endurance, ballet, and flexibility in the competitive performance. The routines vary in length from 2 to 5 min, requiring aerobic endurance with intermittent bursts of anaerobic power. High-intensity movements that are complex and require precise synchronization in a zero-gravity environment must be maintained with performance artistry. Therefore, elite synchronized swimmers need to be both aerobically and anaerobically fit; one study found that the physiological profile (i.e., peak oxygen uptake, blood lactate concentration, and heart rate measured during a 400-m swim) of individual swimmers is positively linked to synchronized swimming skill (Chatard et al., 1999). Studies have found that 45–50% of the time is spent underwater, which necessitates exceptional breath control (Homma, 1994; Chatard et al., 1999). Current requirements for more acrobatic maneuvers may now involve less time spent underwater, but the long training sessions associated with the sport mandate a high level of fitness. Swimmers may be underwater performing choreographed movements for a significant amount of time, perhaps for as long as 1 min, resulting in a significant total cumulative time underwater during elite level performances. Both balance and motor control skills are important in this discipline, as is the capacity to perform the routine in synchrony with teammates and music. The gymnastics-type movements that are performed within the high resistance of water requires that athletes develop a broad range of cardiovascular and musculoskeletal strength, typically attained through running, cycling, swimming, and practicing competition routines. Off season training commonly involves the use of free weights and plyometrics to improve leg and core strength.

The typical training schedule involves the establishment of a quadrennial plan, usually established by national teams, which outlines the training goals and objectives of the 4 years leading up to the Olympic Games. The yearly training plan is divided into macrocycle, mesocycle, and microcycle phases, and the nutritional requirements of synchronized swimmers vary depending on the training phase and the volume and intensity of the work being performed. Ideally, nutritional planning should be periodized within the yearly training plan.

Energy Expenditure

It is difficult to estimate the energy requirements for elite synchronized swimmers, because few studies have focused on this issue (Ebine et al., 2000). Bante et al. (2007) reported that, because of the nature of the sport, it is impossible to continuously measure oxygen consumption during exercise, which makes it difficult to assess energy requirements and the relative contributions of aerobic and anaerobic metabolism. However, researchers used a doubly labeled water method for measuring total energy expenditure (TEE) of elite Japanese synchronized swimmers during moderately intense training and determined that the mean TEE was 11.5 MJ/day (SD = 2.8), or 2,738 kcal/day (SD = 672) (Ebine et al., 2000). There is a need for more research in this area to accurately assess the energy requirements of synchronized swimmers.

Assessment of Nutritional Status

Physical activity increases energy expenditure and, because of heat-creating metabolic inefficiencies in converting fuel to mechanical force, physical activity also increases the rate of sweat production. All athletes, therefore, must find strategies for assuring adequate energy and fluid consumption. In addition, athletes must consider how energy substrate metabolism is affected by the specific type of activities they are doing, and they should replace these substrates in a way that mirrors demand. An increase in energy expenditure also alters the requirement for certain vitamins (particularly B vitamins) and may similarly alter the need for certain minerals, including iron and calcium. A failure to adequately satisfy the increased nutrient requirement through food may place the athlete at higher injury risk, may fail to optimally reduce muscle soreness and enhance muscle recovery, can negatively affect the immune system to increase illness frequency, and may negatively alter both power and endurance. Ideally, the assessment of nutritional status of athletes should include several components, including the following:

- Periodic assessment of food and beverage intake to ensure that tissues are exposed to the needed nutrients in amounts that satisfy the predicted need.
- An annual periodic health examination that looks for signs of nutrient deficiency or toxicity, including a blood and urine test to assess iron, vitamin D status, and hydration state (Fédération Internationale de Natation, 2014).
- Periodic assessment of weight and body composition to ensure that metabolic and fat mass is sustained or, if altered, changed in a desirable way.
- Assessment of bone mineral density (BMD) should be performed periodically on the recommendation of the team physician. Should an athlete be diagnosed with osteopenia or an eating disorder (ED), the assessment of BMD should be more frequent.

There is increasing evidence that the traditional 24-hr energy/nutrient intake assessment may not optimally assess the adequacy of food intake (Deutz et al., 2000). In particular, the timing of protein consumption is a critical factor in sustaining or increasing muscle mass (Paddon-Jones & Rasmussen, 2009; Tipton et al., 2007). There is also evidence that the pre- and postexercise consumption of carbohydrates and protein influence muscle protein synthesis, muscle soreness, and recovery (Gibala, 2002; Cermak et al., 2009). These findings strongly suggest that nutrition assessment should consider the timing of the intake of energy and nutrients, with the goal of avoiding large peaks and valleys in energy balance to ensure optimal utilization of consumed energy substrates and to optimize performance and recovery.

Assessment of Body Composition

Body mass and composition are important for achieving optimal athletic performance, regardless of the sport. Because of the aesthetic nature of synchronized swimming, the pressure to sustain or achieve a fit body profile to match those of teammates and to satisfy the expectations of the sport are high. Although body composition data on synchronized swimmers is limited, there is evidence that aesthetic sport athletes are at risk for developing disordered eating (DE) and ED (Benardot & Thompson, 1999; de Sousa Fortes et al., 2013; Sundgot-Borgen & Garthe, 2011). To exacerbate this problem, many athletes have a tendency to supply the needed energy after it is most needed (i.e., postloading), which results in compromised performance and an undesired change in body composition (Deutz et al., 2000). Several potential reasons exist for why these athletes fail to optimally satisfy total energy requirements, including an inadequate understanding of foods and beverages that are best for performance enhancement; scarce availability of foods and beverages before, during, and after exercise; sport-specific traditions that perpetuate poor eating and hydration habits; and a tendency for athletes to model behavior after celebrities, even if their food/beverage consumption behaviors are inadequate (Benardot, 2007). Many athletes have eating anxiety, with a fear that eating exercise-appropriate foods and beverages will negatively alter body composition and increase body mass (Haase et al., 2002; Krane et al., 2001; Vardar et al., 2007). There may also be confusion with what the athlete wishes to accomplish when dieting, because leanness (the desired outcome) is not the same as thinness (the likely outcome). A sustained weight composed of proportionately more muscle and less fat is clearly better for both performance and appearance than a lower body mass with proportionately less muscle and more fat (Benardot, 2007). Therefore, weight per se may be an inappropriate metric with which to determine whether eating and exercise strategies are achieving the desired result. Rather, a regular program of body composition assessment may be more appropriate in helping the athlete determine whether the strategies they follow are helping them attain a physique that will benefit their performance.

There are several strategies for assessing body composition that vary in cost, accuracy, reliability, and portability, ranging from skinfolds measurements to bioelectrical impedance analysis and dual-energy x-ray absorptiometry). Ideally, health professionals should select a strategy that enables assessments of lean mass and fat mass at regular intervals to discern whether changes in body composition suggest successful (e.g., gradual increases in muscle to fat ratios) or unsuccessful (e.g., gradual decreases in muscle to fat ratios) eating and exercise behavior. Although there has been concern that swimming occurs a zero-gravity environment lacking the ballistic stimulation of the skeleton seen in other sports, there is no evidence to suggest that healthy swimmers are at higher risk of low BMD than athletes participating in other sports (Gómez-Bruton et al., 2013).

There are concerns with assessing body composition in athletes. One concern is that athletes are highly competitive, and providing specific weight and body composition values to the athlete may result in their making inappropriate comparisons with their peers. Therefore, athletes should be informed that the purpose of the assessment is to monitor any potentially unhealthy *changes* that may occur and to determine whether exercise and eating strategies are having the desired impact. Strategies for achieving this include the following (Benardot, 2002):

- Obtaining body composition values with only one athlete at a time.
- Giving athletes information on body composition using phrases such as "within the desirable range" rather than a raw value, such as "your body fat level is 18%."
- Providing athletes with information on how they have changed between assessments, rather than offering the current value (e.g., "your muscle mass has increased since the last measurement").
- Increasing the focus on muscle mass and decreasing the focus on body fat.
- Using body composition values as a means of helping to explain changes in objectively measured performance outcomes.
- Focusing on the changes in body composition as the basis of recommending dietary changes to either sustain positive changes or reverse negative changes.
- Avoiding any punitive action as a result of the assessed values.

Nutritional Recommendations for Synchronized Swimming

Nutritional Strategies for Training

Olympic-level synchronized swimmers have a high-volume and high-intensity training program of 7 hr/day for 6 days/week (Mountjoy, 2009). The training regimen involves not only the synchro-specific pool training but also additional training in weights, ballet, Pilates, speed swimming, acrobatics, flexibility, and conditioning. Because of the nature of the training schedule, which traditionally involves minimal and limited breaks, athletes have reported difficulty in consuming adequate energy and fluid. Food choices should be relatively high in carbohydrates, nutrient dense, easily accessible, and easily digestible to enable training at a high intensity during training sessions. Ideally, athletes should choose a well-balanced diet that is sufficient in energy, carbohydrates, and protein to optimize training performance. The nutritional plan should also consider appropriate timing of meals and snacks; coaches should allow sufficient breaks to allow for proper fueling and hydration. A unique characteristic of synchronized swimming involves spending a large percentage of the training upside down in the water. Athletes often report gastrointestinal upset if they eat large volumes of food or certain types of high-fiber, gas-producing foods, such as peppers and onions. Using an antacid can be useful in prevention of gastrointestinal upset.

Energy Requirements

Energy requirements vary depending on the period of the year and the phase of training. The most challenging energy demands occur in the months leading up to a major international competition because of the increased training load. Energy intake should be periodized and adjusted to dynamically match the differential energy expenditures associated with different levels of training.

Synchronized swimming is an aesthetic sport, emphasizing leanness. Athletes may consume an insufficient number of calorics when trying to manipulate body composition (Burke et al., 2001). Low energy intake can result in loss of muscle mass, menstrual dysfunction, compromised bone health (Rodriguez et al., 2009), and an increased risk of infection (Rauh et al., 2010). Synchronized swimmers require sufficient calories with a focus on the macronutrients carbohydrates and protein.

Carbohydrates

The primary goal of ingesting carbohydrates is to provide fuel for the muscles. Synchronized swimmers should ingest adequate amounts of carbohydrates before, during, and after training to prevent carbohydrate depletion, giving special attention to periods of intense training and competition (Burke et al., 2001).

Carbohydrate recommendations should be given in grams relative to the athlete's body weight. Carbohydrate recommendations range from 6 to 10 g/kg of body weight per day depending on the sport, athlete gender, environmental conditions, and total energy requirements/expenditure (Rodriguez et al., 2009). Burke et al. (2004) recommend a carbohydrate range of 5–7 g/kg/day for general training. These ranges are useful in providing individual counseling to meet carbohydrate targets and provide adjustments depending on the time of year, body composition, and training goals. It is important to consider that female athletes that restrict total calories to decrease body weight may have difficulty in achieving carbohydrate recommendations (Burke et al., 2001). Given the aesthetic nature of synchronized swimming, the recommendation range of 5–7 g/kg/day is recommended. Carbohydrate ingestion should occur at frequent intervals throughout the day, including before, during, and after training.

Protein

According to Rodriguez et al. (2009), recommendations for protein intake range from 1.2 to 1.7 g/kg of body weight per day for endurance and strength-trained athletes. Because of the training demands, elite synchronized swimmers should aim for a protein range of 1.5–1.7 g/kg of body weight/day as a starting point, with an emphasis on timing. This range provides flexibility and should be individualized on the basis of the athlete's requirements. Athletes should be encouraged to meet protein requirements by including high-quality, protein-rich foods at all meals and snacks, evenly spaced throughout the day. Adequate energy intake must be sufficient for the optimal use of protein in the body. Energy balance is key when working with athletes, because this can spare the body from using protein as an energy source.

Fat

Fat is also an important macronutrient in the diet of an elite synchronized swimmer. Fat provides essential fatty acids, fat-soluble vitamins, and energy. Fat should be 20–25% of total energy intake (Rodriguez et al., 2009). A diet too low in fat has the potential to compromise the immune system. The challenge in working with diet-conscious athletes is that there tends to be an underlying fear of consuming foods containing fat.

Key Micronutrient Requirements

Energy metabolism is, to a large extent, dependent on the coavailability of B vitamins with energy substrates, and certain minerals are also important for the energy metabolic processes through oxygen transfer and nerve impulse transmission of muscle cells. Because of nutrient enrichment and fortification, B-vitamin deficiency is not commonly found among athletes. Deficiencies of certain minerals, particularly iron and calcium, are more commonly found in athletes. There is concern that athletes may be over reliant on high-dose supplemental intakes of vitamins and minerals (Maughan et al., 2007). Although high intake of certain vitamins and minerals may be benign, consumption of excess micronutrients via supplementation may also create difficulties. As an example, vitamins E and B6 have been found to have toxicity potential when taken over a long period in typical supplemental doses (Bernstein, 1990; Miller et al., 2005). There is also evidence that taking high-dose supplements may impair the immune system and, for instance, enhance exercise-induced lipid peroxidation and inflammation (Nieman et al., 2004). Of very real concern is that athletes may consume prohibited substances, which are often included in vitamin supplements but not listed on the label (Maughan, 2005; Maughan et al., 2007). Taken together, these findings suggest that athletes should use foods, rather than supplements, as the primary delivery systems for satisfying micronutrient requirements. Of particular concern are iron, calcium, and vitamin D.

Iron

Iron is required for oxygen-transporting compounds (primarily hemoglobin and myoglobin), and a deficiency of iron may lead to inadequate oxygen-carrying capacity, which negatively affects endurance and attention span in athletes. Women of child-bearing age, vegetarians, and athletes are at higher deficiency risk because of either increased requirements or inadequate intakes. A vegetarian athlete, therefore, will be at even higher risk of deficiency because of a combination of factors (Benardot, 2012):

- Vegetarians may consume foods with a poor concentration of iron.
- Vegetable sources of iron have both lower iron concentrations and lower iron absorption rates than iron in meats.
- Iron-containing red blood cells may break down at a faster rate because of increased activity-associated intravascular compression, resulting in hemolysis. This may result in more iron being lost in the urine (Shaskey & Green, 2000).
- Although a low amount of iron is lost in sweat, the higher sweat rates of athletes increase total iron losses (Selby & Eichner, 1986; Waller & Haymes, 1996).

A study reporting combined iron status of collegiate swimmers and divers reported marginal iron status among the group; median serum ferritin was 12.7 μg/L (range = 1.6–113.5 μg/L; Petersen et al., 2006). Athletes in similar aesthetic sports, such as gymnastics, have reported dietary iron intake below the recommended level (15 mg/day in girls and women between 11 and 24 years old). This has numerous implications for resistance to disease, growth, strength, and the ability to concentrate (Loosli, 1993). There is little information on hemoglobin, hematocrit, and ferritin status of aesthetic sport athletes that would clarify whether intake affects functional and stored iron. A study on artistic gymnasts, however, suggests that a significant proportion have low serum iron and a relatively high rate of anemia (Lindholm et al., 1995). It is estimated that the typical diet in industrialized nations provides 6 mg of iron per 4.2 MJ (1,000 kcal) of energy. This requires that synchronized swimmers have an average energy consumption of approximately 2,500 kcal/day to satisfy the dietary intake of iron.

Calcium

Calcium has multiple functions, including mineralization of bones and teeth, sustaining normal blood pH, clotting blood, and nerve transmission. When taken as a supplement, athletes typically consume calcium to ensure BMD is adequate rather than for any specific performance enhancement. Although no studies have assessed calcium status (i.e., BMD) of synchronized swimmers, there are data on other athletes in aesthetic sports. Elite gymnasts often demonstrate an inadequate intake of energy and several nutrients, primarily iron and calcium; a low intake of calcium, coupled with a low vitamin D exposure/intake, may predispose athletes to stress fractures (Lovell, 2008). Several studies have demonstrated a relationship between injury frequency and nutritional factors. Adequate calcium intake of 1,500 mg/day may impart some degree of safety in helping to reduce fracture risk (Heaney, 1991), and if it is not possible to obtain sufficient calcium through food consumption, calcium supplementation has been found to be effective in increasing BMD in children (Johnston et al., 1992). Female athletes with ED-associated amenorrhea may develop low BMD because of a combination of inadequate consumption, high cortisol levels (associated with low blood sugar and inadequate energy intake), and low estrogen (an inhibitor of osteoclast activity). Although synchronized swimming is not a sport in which athletes experience ballistic stress on the skeleton that could increase fracture risk, the multiple functions of calcium should encourage these athletes to ensure a daily intake of between 1,000 and 1,500 mg, preferably through food or through a combination of foods and supplements.

Vitamin D

Vitamin D is known for promoting the mineralization of bones and teeth by enhancing calcium and phosphorus absorption, but vitamin D has multiple other functions that influence the athletic endeavor. These include enhancing muscle contraction, muscle protein anabolism, improving immune function, and enhancing antiinflammatory action (Cannell et al., 2009; Hamilton, 2010; Schubert & DeLuca, 2010; Williams, 2005).

One study has also indicated that nondietary factors may also serve to compromise nutrient status in athletes who train indoors. In this study, vitamin D status was found to be below optimal values in a significant proportion of these athletes (Lovell, 2008). However, in a study investigating vitamin D status and supplementation in collegiate swimmers and divers training indoors, researchers observed a low prevalence of vitamin D insufficiency (25-hydroxy vitamin D < 32 ng/ml), and an absence of vitamin D deficiency (25-hydroxy vitamin D < 20 ng/ml; Lewis et al., 2013). There is a history of ultraviolet light therapy to ensure adequate vitamin D status for athletes.

Sunlamps were used by German swimmers, and the effect was considered sufficiently positive that some considered it a form of illegal doping (Cannell et al., 2009). Given its importance, synchronized swimmers should consider having a periodic blood test to assess vitamin D status, perhaps as a regular component of the periodic health examination.

Fluid/Hydration Strategies

Maintenance of hydration during exercise is strongly associated with a high level of athletic performance. Failure to do so compromises the performance by lowering blood volume, thereby compromising the sweat rate (and therefore the cooling capacity), interfering with the optimum delivery of nutrients to working muscles, and interfering with the removal of metabolic by-products from working muscles (Benardot, 2012). The concentration of sodium (20–80 mmol/L) and chloride (20–60 mmol/L) in sweat are far higher than other electrolytes (Maughan, 1994). Given the normal reduction in blood glucose during exercise, the hydration beverage should contain approximately 100 mg of sodium per 240 ml and approximately 6% carbohydrate (Rodriguez et al., 2009). The goal, therefore, is to follow a hydration strategy during exercise and competition to prevent dehydration but not to provide so much fluid that hyperhydration and weight gain occur. During recovery, rehydration beverage should replace water and sodium losses ("IOC consensus statement" 2010). Dehydration, defined as a body water deficit in excess of 2–3% of body mass, decreases exercise performance in laboratory settings. It is important for synchronized swimmers to consume sufficient fluids before, during, and after exercise to sustain health and performance. Ideally, a hydration plan should be developed that can sustain the hydration state during both training and competition.

Recovery Protocol

The goal of recovery nutrition is to replace fluid and muscle glycogen and to optimize restoration of muscle glycogen between training sessions. Therefore, athletes should be encouraged to consume foods high in carbohydrate within the first 15–30 min after training, because the timing of postexercise carbohydrate intake affects glycogen synthesis. Recovery guidelines from Burke et al. (2004) recommend 1.0–1.2 g of carbohydrate per kg of body weight consumed at frequent intervals (0–4 hr) immediately after training. Nutrient-rich carbohydrate foods with a moderate to high glycemic index provide a readily available source for muscle glycogen synthesis and should be the foods of choice in recovery meals (Burke et al., 2004). Drinking additional fluid during recovery is also important. According to Burke et al. (2006), consuming small amounts of protein within the carbohydrate-rich meals can also help athletes achieve other nutritional goals such as adequate protein intake.

Synchronized swimmers should fine-tune their specific recovery requirements on the basis of their individual goals, training needs, and timing of the training and competition schedule. Because there can be a tendency to restrict eating, attention should be given to ensuring adequate energy intake, because this is very important for achieving glycogen recovery.

Nutritional Strategies for Competition

Before major events, the precompetition period is characterized by high volume and intensity of training that is mainly in the water. The nutrition goals before the event are to prevent hunger, ensure adequate hydration, and top up carbohydrate stores. For 1–4 hr before the competitive event, athletes should consume mainly carbohydrates, because they are digested faster. Food choices should be familiar and easy to digest. Fat slows down digestion and is not recommended. High-fiber and gas-producing foods should also be avoided before competing.

After the competition event, proper recovery protocol should be followed to restore muscle glycogen, prevent dehydration, and help prepare the athlete for upcoming events. Challenges that can prevent the athlete from ingesting carbohydrate immediately after competing can include media (interviews), drug testing, medal ceremonies/award presentations, and team celebrations.

Relative Energy Deficiency in Sport

Relative Energy Deficiency in Sport (RED-S), formerly known as the Female Athlete Triad, is defined as a syndrome resulting from an energy deficiency relative to the balance between dietary energy intake and the energy expenditure required to support homeostasis, health, and the activities of daily living, growth, and sporting activities. RED-S affects many aspects of physiological function, including metabolic rate, menstrual function, bone health, immunity, protein synthesis, and cardiovascular and psychological health (Mountjoy et al., 2014). Energy availability is defined as the balance between dietary caloric intake and exercise energy expenditure (Nattiv et al., 2007). When an athlete expends more calories from exercise than are consumed through the diet, the athlete is said to have a low energy balance. This can occur when the athlete restricts intake through an ED or DE or through excess energy expenditure through exercise, which may be deliberate or inadvertent (Loucks, 2004).

Although no data in the literature are specific to synchronized swimming, there is evidence that the RED-S exists in aesthetic, endurance sports and weight class sports (Constantini & Warren, 1995). In professional ballet dancing, the prevalence of low energy availability was 77% (Hoch et al., 2011). Relevant to synchronized swimming are the results of a study by Rauh et al. (2010) that clearly demonstrate the increased risk of musculoskeletal injury in the athlete suffering from low BMD, menstrual abnormality, and DE.

The hypothalamic-pituitary-gonadal hormone axis is disrupted by the low energy availability, leading to menstrual dysfunction. The menstrual dysfunction most commonly associated with the RED-S is functional hypothalamic amenorrhea. Other menstrual abnormalities seen are luteal-phase dysfunction and anovulation. Long-term physical consequences of menstrual dysfunction include osteopenia/osteoporosis and infertility. Prevalence studies estimate that up to 50% of exercising women have subtle menstrual abnormalities (anovulation, luteal-phase disorder) and 33% suffer from amenorrhea (De Souza, 2010). Sambanis et al. (2003) found that elite synchronized swimmers had a delay in menarche of 0.6 years compared with athletes from other sports. Ferrand et al. (2007) reported a 30.3% prevalence rate of menstrual dysfunction in synchronized swimmers; however, the rest of the study group was on the oral contraceptive pill, thus potentially masking the true incidence. A study on synchronized swimmers in Great Britain by Ramsay & Wolman (2001) was similarly challenged.

Both hormonal disruption and nutritional deficits contribute to the development of poor bone health related to RED-S. The period of maximum bone accrual is during adolescence, when the synchronized swimmer is training heavily. Disruption to bone formation during this critical time period may be irreversible. Evidence shows that the effect on bone formation is cumulative, with multiple risk factors (Gibbs et al., 2013). The prevalence of osteopenia in athletes is estimated at between 22 and 50% and that of osteoporosis at 13% (Khan et al., 2002). Studies done by Roby et al. (1988) and Liang et al. (2005) demonstrated lower BMD in the wrists of synchronized swimmers compared with gymnasts and untrained control subjects. Similar results were found for lower limb and lumbar measurements (Tanaka et al., 2006).

Disordered Eating and Eating Disorders

Body composition is an important performance parameter for the synchronized swimmer. Although many athletes may be genetically predisposed to the desired anthropometric shape of the ideal synchronized swimmer, other athletes struggle with the pressure to conform to the required thin physique. This pressure can lead to DE and/or EDs. According to the American Psychiatric Association's (2013) *Diagnostic and Statistical Manual of Mental Disorders*, 5th edition (DSM-V), the clinical EDs include anorexia nervosa, bulimia nervosa, binge eating disorder, and other specified (or unspecified) feeding or eating disorders.

The prevalence of ED is reported to be 31% in thin-build sports (Byrne & McLean, 2002) and 25% in endurance and aesthetic sports (Sundgot-Borgen & Torstveit, 2004). Prevalence data show that athletes in sports that emphasize leanness or low body weight have a higher frequency of DE (Rosendahl et al., 2009). Prevalence data by Lee (2005) showed higher eating disturbance scores on the EAT 26 questionnaire in synchronized swimming and rhythmic gymnastics (30%) compared with other sports (5%). A study performed in Greece showed that synchronized swimmers had higher scores on the EAT13 questionnaire for EDs compared with swimmers and water polo players (Douka et al., 2008). Ferrand et al. (2007) showed that more than half of college-level synchronized swimmers showed distorted body image with dissatisfaction despite being in the healthy weight range, with a high incidence of self-induced fasting and/or vomiting, use of diuretics and/or laxatives, and excessive exercise.

The health consequences of DE/EDs are vast and can be fatal. Every body system can be affected, including the reproductive, cardiovascular, skeletal, renal, gastrointestinal, endocrine, and central nervous systems. Age-related physical consequences of ED can occur during adolescence, such as delayed puberty, bone-growth retardation, and decreased bone deposition. Psychological consequences include depression, anxiety, and suicidal ideation as well as athletic performance consequences to DE/EDs.

Prevention of Disordered Eating/Eating Disorders in Synchronized Swimming

FINA, in cooperation with the IOC Medical Commission, is looking for ways to decrease the health risks associated with lean sports (Mountjoy, 2008). For example, National Federations or National Olympic Committees can develop and implement healthy body composition policies and protocols to minimize the pressure on synchronized swimmers to be thin. One such strategy is a school-based intervention implemented in Norway to prevent the development of ED. This randomized control trial showed that it is feasible through a school-based intervention to decrease the development of new cases of ED and symptoms associated with ED in adolescent female athletes (Martinsen et al., 2014). Another strategy is Synchro Canada's Weight Management Protocol. This document reviews the science and rationale for body composition measurement and outlines the personnel involved, the level of access to personal athlete information, the time intervals for measurement, and the standardization of body composition measurement. Clear procedures for the management of changes in body composition are also outlined (Synchro Canada 2014).

Research Required to Determine

- The ideal body composition variation limits in the training phase versus the competition phase
- The total energy expenditure in synchronized swimming
- Carbohydrate, protein, and fat requirements specific to synchronized swimming
- Information on hemoglobin, hematocrit, and ferritin status of aesthetic sport athletes
- Calcium and vitamin D status in synchronized swimmers

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References

American Psychiatric Association. (2013). Feeding and eating disorders. In *Diagnostic and Statistical Manual of Mental Disorders* (5th ed., pp. 329–354). Washington, DC: Author.

Bante, S., Bogdanis, G.C., Chairopoulou, C., & Maridaki, M. (2007). Cardiorespiratory and metabolic responses to a simulated synchronized swimming routine in senior and comen national level athletes. *Journal of Sports Medicine and Physical Fitness, 47,* 291–299. PubMed

Benardot, D. (2012). *Advanced Sports Nutrition* (2nd ed.). Champaign, Urbana: Human Kinetics Publisher.

Benardot, D. (2002). Guideline 2e: Assessment of body composition. In A. Editor & B. Editor (eds.). *NCAA sports medicine handbook*. (14th ed., pp. 34–38). Indianapolis, IN: National Collegiate Athletic Association.

Benardot, D. (2007). Timing of energy and fluid intake: New concepts for weight control and hydration. *ACSM's Health & Fitness Journal, 11*(4), 13–19. doi:10.1249/01.FIT.0000281226.23643.de

Benardot, D., & Thompson, W.R. (1999). Energy from food for physical activity: Enough and on time. *ACSM's Health and Fitness Journal, 3*(4), 14–18. doi:10.1249/00135124-199907000-00009

Bernstein, A.L. (1990). Vitamin B6 in clinical neurology. *Annals of the New York Academy of Sciences, 585,* 250–260. PubMed doi:10.1111/j.1749-6632.1990.tb28058.x

Byrne, S., & McLean, N. (2002). Elite athletes: Effects of the pressure to be thin. *Journal of Science and Medicine in Sport, 5,* 80–94. PubMed doi:10.1016/S1440-2440(02)80029-9

Burke, L.M., Cox, G., Cummings, N., & Desbrow, B. (2001). Guidelines for daily carbohydrate intake: Do athletes achive them? *Sports Medicine, 31,* 267–299. PubMed doi:10.2165/00007256-200131040-00003

Burke, L.M., Kiens, B., & Ivy, I. (2004). Carbohydrate and fat for training and recovery. *Journal of Sports Sciences, 22,* 15–30. PubMed doi:10.1080/0264041031000140527

Burke, L.M., Loucks, A., & Broad, N. (2006). Energy and carbohydrate for training and recovery. *Journal of Sports Sciences, 24,* 675–685. PubMed doi:10.1080/02640410500482602

Cannell, J.J., Hollis, B.W., Sorenson, M.B., Taft, T.N., & Anderson, J.J. (2009). Athletic performance and vitamin D. *Medicine & Science in Sports & Exercise, 41,* 1102–1110. PubMed doi:10.1249/MSS.0b013e3181930c2b

Cermak, N.M., Solheim, A.S., Gardner, M.S., Tarnopolsky, M.A., & Gibala, M.J. (2009). Muscle metabolism during exercise with carbohydrate ingestion. *Medicine & Science in Sports & Exercise, 41,* 2158–2164. PubMed doi:10.1249/MSS.0b013e3181ac10bf

Chatard, J.C., Mujika, I., Chantegraille, M.C., & Kostucha, J. (1999). Performance and physiological responses to a 5-week synchronized swimming technical training programme in humans. *European Journal of Applied Physiology, 79,* 479–483. PubMed doi:10.1007/s004210050540

Constantini, N.W., & Warren, M. (1995). Menstrual dysfunction in swimmers: A dinstinct entity. *Journal of Clinical Endocrinology and Metabolism, 80,* 2740–2744. PubMed

Deutz, R.C., Benardot, D., Martin, D., & Cody, M. (2000). Relationship between energy deficits and body composition in elite female gymnasts and runners. *Medicine & Science in Sports & Exercise, 32,* 659–668. PubMed doi:10.1097/00005768-200003000-00017

De Sousa Fortes, L., Neves, C.M., Filgueiras, J.F., Almeida, S.S., & Ferreira, M.E.C. (2013). Body dissatisfaction, psychological commitment to exercise and eating behavior in young athletes from aesthetic sports. *Brazilian Journal of Kinanthropometry and Human Performance, 15,* 695–704. doi:10.5007/1980-0037.2013v15n6p695

De Souza, M.J., Toombs, R., Scheid, J., O'Donnell, E., West, S., & Williams, N. (2010). High prevalence of subtle and severe menstrual disturbances in exercising women: Confirmation using daily hormone measures. *Human Reproduction, 25,* 491–503. PubMed doi:10.1093/humrep/dep411

Douka, A., Skordilis, E., Koutsouki, D., & Theodorakis, Y. (2008). Prevalence of eating disorders among elite female athletes in aquatic sports. *Inquiries in Sport & Physical Education, 6,* 87–96.

Ebine, N., Feng, J.Y., Homma, M., Saitoh, S., & Jones, P.J.H. (2000). Total energy expenditure of elite synchronized swimmers measured by the doubly labelled water method. *European Journal of Applied Physiology, 83,* 1–6. PubMed doi:10.1007/s004210000253

Ferrand, C., Magnan, C., Rouveix, M., & Filare, E. (2007). Disordered eating, perfectionism and body-esteem of elite synchronized swimmers. *European Journal of Sport Science, 7,* 223–230. doi:10.1080/17461390701722168

Fédération Internationale de Natation. (2013). Synchronized swimming rules 2013–2017. Retrieved from http://www.fina.org/H2O/docs/rules/FINAsyrules_20132017.pdf

Fédération Internationale de Natation. (2014). Aquatic periodic health examination. Retrieved from http://www.fina.org/project/PHE_form.pdf

Garner D.M., Olmsted M.P., Bohr Y., and Garfinkel P.E. (1982). The Eating Attitudes Test: Psychometric features and clinical correlates. *Psychological Medicine, 12,* 871–878.

Gibala, M.J. (2002). Dietary protein, amino acid supplements, and recovery from exercise. *GSSI Sports Science Exchange, 15,* 1–4.

Gibbs, J.C., Nattiv, A., Barrack, M.T., Williams, N.I., Rauh, M.J., Nichols, J.F., & De Souza, M.J. (2014). Low bone density risk is higher in exercising women with multiple triad risk factors. *Medicine & Science in Sports & Exercise, 46*, 167–176. PubMed doi:10.1249/MSS.0b013e3182a03b8b

Gómez-Bruton, A., Gónzalez-Agüero, A., Gómez-Cabello, A., Casajús, J.A., & Vincente-Rodríguez, G. (2013). Is bone tissue really affected by swimming? A systematic review. *PLoS ONE, 8*(8), Article e70119. doi:10.1371/journal.pone.0070119. PubMed

Haase, A.M., Prapavessis, H., & Owens, R.G. (2002). Perfectionism, social physique anxiety and disordered eating: A comparison of male and female elite athletes. *Psychology of Sport and Exercise, 3,* 209–222. doi:10.1016/S1469-0292(01)00018-8

Hamilton, B. (2010). Vitamin D and human skeletal muscle. *Scandinavian Journal of Medicine & Science in Sports, 20,* 182–190. PubMed

Heaney, R.P. (1991). Effect of calcium on skeletal development, bone loss, and risk of fractures. *American Journal of Medicine, 91*(Suppl. 5B), 23S–28S. PubMed doi:10.1016/0002-9343(91)90243-Q

Hoch, A.Z., Papanek, P., Szabo, A., Widslansky, M., Schimke, J., & Gutterman, D. (2011). Association between the female athlete triad and endothelial dysfunction in dancers. *Clinical Journal of Sport Medicine, 21,* 119–125. PubMed doi:10.1097/JSM.0b013e3182042a9a

Homma, M. (1994). The components and the time of "face in" of the routines in synchronized swimming. In M. Miyashi, Y. Mutoh, & A.B. Richardson (Eds.), *Medicine and science in aquatic sports* (pp. 149–154). Basel, Switzerland: Karger.

IOC consensus statement on sports nutrition. (2010). *Journal of Sports Sciences, 29*(Suppl. 1), S3–S4. doi:10.1080/02640414.2011.619349

Johnston, C.C., Miller, J.Z., Slemenda, C.W., Reister, T.K., Hui, S., Christian, J.C., & Peacock, M. (1992). Calcium supplementation and increases in bone mineral density in children. *New England Journal of Medicine, 327,* 82–87. PubMed doi:10.1056/NEJM199207093270204

Khan, K.M., Liu-Ambrose, T., Sran, M., Ashe, M., Donaldson, M., & Wark, J. (2002). New criteria for female athlete triad syndrome? As osteoporosis is rare, should osteopenia be among the criteria for defining the female athlete triad syndrome? *British Journal of Sports Medicine, 36,* 10–13. PubMed doi:10.1136/bjsm.36.1.10

Krane, V., Waldron, J., Stiles-Shipley, J A., & Michalenok, J. (2001). Relationships among body satisfaction, social physique anxiety, and eating behaviors in female athletes and exercisers. *Journal of Sport Behavior, 24*, 247–265.

Lee, D. (2005). Eating attitudes, weight concerns, dietary intake and menstruation among Korean elite female athletes. *Nutritional Sciences, 8,* 118–124.

Lewis, R.M., Redzi, M., & Thomas, D.T. (2013). The effects of season-long vitamin d supplementation on collegiate swimmers and divers. *International Journal of Sport Nutrition and Exercise Metabolism, 23,* 431–440.

Liang, M.T., Arnaud, S., Steele, C., Hatch, P., & Moreno, A. (2005). Ulnar and tibial bending stiffness as an index of bone strength in synchronized swimming and gymnasts. *European Journal of Applied Physiology, 94,* 400–407. PubMed doi:10.1007/s00421-005-1351-2

Lindholm, C., Hagenfeldt, K., & Hagman, U. (1995). A nutrition study in juvenile elite gymnasts. *Acta Paediatrica, 84,* 273–277. PubMed doi:10.1111/j.1651-2227.1995.tb13628.x

Loosli, A.R. (1993). Reversing sports-related iron and zinc deficiencies. *The Physician and Sportsmedicine, 21,* 70–78.

Loucks, A.B. (2004). Energy balance and body composition in sports and exercise. *Journal of Sports Sciences, 22,* 1–14. PubMed doi:10.1080/0264041031000140518

Lovell, G. (2008). Vitamin D status of females in an elite gymnastics program. *Clinical Journal of Sport Medicine, 18,* 159–161. PubMed doi:10.1097/JSM.0b013e3181650eee

Martinsen, M., Bahr, R., Borresen, R., Holme, I., Pensgaard, A., & Sundgot-Borge, J. (2014).Preventing eating disorders among young elite athletes: A randomized controlled trial. *Medicine & Science in Sports & Exercise, 46,* 435–447. PubMed doi:10.1249/MSS.0b013e3182a702fc

Maughan, R.J. (1994). Fluid and electrolyte loss and replacement in exercise. In M. Harries, C. Williams, W.D. Stanish, & L.J. Micheli (Eds.), *Oxford textbook of sports medicine* (pp. 82–93). Oxford, England: Oxford University Press. Maughan, R.J. (2005). Contamination of dietary supplements and positive drug tests in sport. *Journal of Sports Sciences, 23,* 883–889. PubMed doi:10.1080/02640410400023258

Maughan, R.J., Depiesse, F., & Geyer, H. (2007). The use of dietary supplements by athletes. *Journal of Sports Sciences, 25* (Suppl. 1), S103–S113. PubMed doi:10.1080/02640410701607395

Miller, E.R., Pastor-Barriuso, R., Dalal, D., Riemersma, R.A., Appel, L.J., & Guallar, E. (2005). Meta-analysis: High-dosage vitamin E supplementation may increase all-cause mortality. *Annals of Internal Medicine, 142,* 37–46. PubMed doi:10.7326/0003-4819-142-1-200501040-00110

Mountjoy, M. (1999). The basics in synchronized swimming and its injuries. *Clinics in Sports Medicine, 18,* 321–336. PubMed doi:10.1016/S0278-5919(05)70148-4

Mountjoy, M. (2008). Weight control strategies of Olympic athletes striving for leanness: What can be done to make sport a safer environment? *Clinical Journal of Sport Medicine, 18,* 2–4. PubMed doi:10.1097/JSM.0b013e3181635664

Mountjoy, M. (2009). Injuries and medical issues in the synchronized Olympic sports. *Current Sports Medicine Reports, 8,* 255–261. PubMed doi:10.1249/JSR.0b013e3181b84a09

Mountjoy, M., Sundgot-Borgen, J., Burke, L., Carter, S., Constantini, N., Lebrun, C., . . . Ljungqvist, A. (2014).The IOC Consensus Statement: Beyond the female athlete triad—Relative energy deficiency in sport. *British Journal of Sports Medicine, 48,* 491–497. PubMed

Nattiv, A., Loucks, A.B., Manore, M.M., Sanborn, C.F., Sundgot-Borgen, J., & Warren, M.P. (2007). American College of Sports Medicine position stand. The female athlete triad. *Medicine & Science in Sports & Exercise, 39,* 1867–1882. PubMed doi:10.1249/mss.0b013e318149f111

Nieman, D.C., Henson, D.A., McAnulty, S.R., McAnulty, L.S., Morrow, J.S., Ahmed, A., & Heward, C.B. (2004). Vitamin E and immunity after the Kona Triathlon World Championship. *Medicine & Science in Sports & Exercise, 36,* 1328–1335. PubMed doi:10.1249/01.MSS.0000135778.57355.CA

Paddon-Jones, D., & Rasmussen, B.B. (2009). Dietary protein recommendations and the prevention of sarcopenia: Protein amino acid metabolism and therapy. *Current Opinion in Clinical Nutrition and Metabolic Care, 12,* 86–90. PubMed doi:10.1097/MCO.0b013e32831cef8b

Petersen, H.L., Peterson, C.T., Reddy, M.B., Hanson, K.B., Swain, J.H., Sharp, R.L., & Alekel, D.L. (2006). Body composition, dietary intake, and iron status of female collegiate swimmers and divers. *International Journal of Sport Nutrition and Exercise Metabolism, 16,* 281–295. PubMed

Ramsay, R., & Wolman, R. (2001). Are synchronized swimmers at risk of amenorrhea? *British Journal of Sports Medicine, 35,* 242–244. PubMed doi:10.1136/bjsm.35.4.242

Rauh, M.H., Nichols, J., & Barrack, M. (2010). Relationships among injury and disordered eating, menstrual dysfunction, and low bone mineral density in high school athletes: A prospective study. *Journal of Athletic Training, 45,* 243–252. PubMed doi:10.4085/1062-6050-45.3.243

Roby, F., Atwater, A., Going, S., Lohman, T., Puhl, J., & Tucker, M. (1988). Bone mineral content in synchronzied swimmers. In Proceedings of the First IOC World Congress on Sports Sciences, October 28 1989–November 3 1989 Colorado Springs, CO: US Olympic Committee.

Rodriguez, N R., DiMarco, N M., Langley, S., American Dietetic Association, Dietitians of Canada & American College of Sports Medicine. (2009). Position of the American Dietetic Association, Dietitians of Canada and the American College of Sports Medicine. Nutrition and athletic performance. *Journal of the American Dietetic Association, 109,* 509–527. PubMed doi:10.1016/j.jada.2009.01.005

Rosendahl, J., Bormann, B., Aschenbrenner, K., Aschenbrenner, F., & Strauss, B. (2009). Dieting and disordered eating in German high school athletes and non-athletes. *Scandinavian Journal of Medicine & Science in Sports, 19*(5), 731–739. PubMed doi:10.1111/j.1600-0838.2008.00821.x

Sambanis, M., Kofotolis, N., Kalogeropoulou, E., Noussios, G., Sambanis, P., & Kalogeropoulos, J. (2003). A study on the effects on the ovarian cycle of athletic training in different sports. *Journal of Sports, Medicine, and Physical Fitness, 43,* 398–403. PubMed

Schubert, L., & DeLuca, H.F. (2010). Hypophosphatemia is responsible for skeletal muscle weakness of vitamin D deficiency. *Archives of Biochemistry and Biophysics, 500,* 157–161. PubMed doi:10.1016/j.abb.2010.05.029

Selby, G.B., & Eichner, E.R. (1986). Endurance swimming, intravascular hemolysis, anemia, and iron depletion. *American Journal of Medicine, 81,* 791–794. PubMed doi:10.1016/0002-9343(86)90347-5

Shaskey, D.J., & Green, G.A. (2000). Sports haematology. *Sports Medicine, 29,* 27–38. PubMed doi:10.2165/00007256-200029010-00003

Sundgot-Borgen, J., & Garthe, I. (2011). Elite athletes in aesthetic and Olympic weight-class sports and the challenge of body weight and body compositions. *Journal of Sports Sciences, 29*(Supp 1), S101–S114. PubMed doi:10.1080/02640414.2011.565783

Sundgot-Borgen, J., & Torstveit, M. (2004). Prevalence of eating disorders in elite athletes is higher than in the general population. *Clinical Journal of Sport Medicine, 14,* 25–32. PubMed doi:10.1097/00042752-200401000-00005

Tanaka, C., Lida, T., Tawara, Y., Murata, M., Takamatsu, J., Honma, M., & Kawahara, T. (2006). Characteristics of bone density in adolescent synchronized swimmers – Relationships between bone density, daily physical activity and dietary intake. *Japanese Journal of Physical Fitness and Sports Medicine, 55,* 165–174. doi:10.7600/jspfsm.55.165

Tipton, K.D., Elliott, T.A., Cree, M.G., Aarsland, A.A., Sanford, A.P., & Wolfe, R.R. (2007). Stimulation of net muscle protein synthesis by whey protein ingestion before and after exercise. *American Journal of Physiology. Endocrinology and Metabolism, 292,* E71–E76. PubMed doi:10.1152/ajpendo.00166.2006

Vardar, E., Vardar, S.A., & Kurt, C. (2007). Anxiety of young female athletes with disordered eating behaviors. *Eating Behaviors, 8*(2), 143–147. PubMed doi:10.1016/j.eatbeh.2006.03.002

Waller, M.F., & Haymes, E. (1996). The effects of heat and exercise on sweat iron loss. *Medicine & Science in Sports & Exercise, 28,* 197–203. PubMed doi:10.1097/00005768-199602000-00007

Williams, M.H. (2005). Dietary supplements and sports performance: Minerals. *Journal of the International Society of Sports Nutrition, 2,* 43–49. PubMed doi:10.1186/1550-2783-2-1-43