Nutrition and Supplements for Elite Open-Weight Rowing

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Abstract
Competitive rowing events are raced over 2,000 m requiring athletes to have highly developed aerobic and anaerobic systems. Elite rowers therefore undertake training sessions focused on lactate tolerance, strength and power as well as aerobic and anaerobic capacity development, that can amount to a 24-h training week. The training stimuli and consequent metabolic demands of each session in a rowing training program differ depending on type, length, and intensity. Nutrition guidelines for endurance- and power-based sports should be drawn upon; however, individualized and flexible nutrition plans are critical to successfully meet the daily, weekly, and cyclic nutrient requirements of a rower. This review will provide an overview of key nutritional strategies to optimize training and enhance adaptation, and briefly discuss supplement strategies that may support health and enhance performance in elite rowing.

Introduction

Debuting at the Paris games in 1900, rowing is one of the oldest sports staged at all summer Olympics. Competition occurs over 2,000 m, with top finishers advancing into quarterfinals, semifinals, and/or a six-boat final. Races are divided into sculling and sweep with heavyweight and lightweight divisions. Depending on the competition, specific discipline, and number of competitors, athletes must be prepared to compete in two to five races over 2 to 8 d.

International rowing has become increasingly competitive, demonstrated at the 2012 London Olympics, where there was a difference of less than 2 s between gold and silver medals in six out of eight events. Rowing is a highly technical and physiologically challenging sport with very demanding training loads (56). Considered a power sport (55) with a substantial endurance training component, rowing requires significant muscular strength and endurance to overcome oar-water interactions and achieve the high-power outputs necessary throughout a race (56). Weight-supported training (ergometer and on-water) allows for extreme training volumes of up to 24 h·wk^{-1}. Unlike other sports with high aerobic training volumes such as cycling or triathlon, the open-weight rower's size and muscularity exacerbates already substantial energy requirements. Consequently, rowers face many nutritional challenges in order to adapt and perform optimally. The most recently published self-reported energy intakes for rowers range from ~3,700 to 4,900 kcal and ~2,380 to 3,000 kcal for open-weight men and women, respectively (6,8) (Table 1). Consideration of the training phase, athlete level, and current body composition goals makes it difficult to use these values universally. Nonetheless, managing total energy and macronutrient requirements are likely challenges for the elite rower.

Accordingly, this review will discuss key nutritional and supplement strategies to optimize training, enhance adaptation, and support health and performance in rowing. Given the scope of this paper, only nutrition for open-weight rowing will be considered.

Physique Characteristics

Beyond technical skill, psychological and physiological attributes (40), and anthropometric characteristics, including height, body mass (BM), muscle mass, and skinfolds, have been correlated with 2,000-m rowing performance (2). Top-ranked male open-weight rowers are significantly taller, heavier, and more muscular than their lower-ranked competitors, and lower skinfold thicknesses were observed in more highly placed female rowers (38). Recent literature reports that senior female and male rowers are ~178 cm and ~192 cm tall, and weigh ~71 kg and ~88 kg, with ~23% and ~20% body fat, respectively (6). Unpublished data collected from the Canadian national men's training group (194.7 cm, 98.4 kg; sum of eight skinfolds, 56.3 mm) are similar to the anthropometric characteristics described

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1537-890X/1504/252–261
Current Sports Medicine Reports

Table 1.
Energy and macronutrient intake of elite rowers (mean ± SD).

Athlete Population	Sample Size	Method of Data Collection	Energy Intake (kcal)	YTP Phase	BM (kg)	Carbohydrate (g)	Protein (g)	Fat (g)	Reference
Canada, open-weight, men	13	1- to 3-d dietary recall[a]	6,973 ± 809	Midseason, high volume	96 ± 6	946 ± 186	295 ± 48	247 ± 43	Unpublished data; 2015/2016
New Zealand, men[b]	28	7-d food diary	3,714 ± 1,286	Not stated	84 ± 8	510 ± 190	170 ± 70	110 ± 45	Braakhuis et al. (2013)
New Zealand, women[b]	34	7-d food diary	2,571 ± 905	Not stated	69 ± 8	370 ± 160	104 ± 44	91 ± 44	
Lithuania, men	24[c]	24-h dietary recall	3,952 ± 946	Preliminary	88 ± 9	4.6 ± 1.3 $g{\cdot}kg^{-1}$[d]	1.6 ± 0.4 $g{\cdot}kg^{-1}$[d]	2.3 ± 0.8 $g{\cdot}kg^{-1}$[d]	Baranauskas et al. (2015)
Lithuania, women		24-h dietary recall	3,000 ± 606	Preliminary	71 ± 7				
Poland, men	16	6-d food diary	56 ± 14 $kcal{\cdot}kg^{-1}$ (~4,900 kcal)	Various	87 ± 10	6.3 ± 1.4 $g{\cdot}kg^{-1}$[e]	1.6 ± 0.6 $g{\cdot}kg^{-1}$[e]	1.7 ± 0.4 $g{\cdot}kg^{-1}$[e]	Durkalec-Michalski et al. (2015)

[a] Accompanied by visual images.
[b] Open and lightweight rowers included in the study.
[c] Reported as combined.
[d] Reported as combined men and women (grams per kilogram BM).
[e] Reported as grams per kilogram of BM.

in open-weight male rowers assessed at the 2000 Summer Olympic Games (38).

Nutrition for Training

Internationally competitive rowers undertake up to 14 training sessions per week, depending on the phase of the yearly training plan (YTP) (see Ref. [55] for review). Training typically focuses on aerobic and anaerobic capacity development, lactate tolerance, as well as strength and power development (56). Given the large contribution aerobic metabolism plays in race performance (40), high-volume, endurance-based training makes up the majority of the rowing program.

To our knowledge, there is no published literature detailing a rower's daily energy expenditure using direct or indirect measurements. Rowers' mean daily energy requirements, estimated using common prediction equations, were reported as 5,303 kcal (men) and 4,258 kcal (women), and self-reported intakes of 3,852 kcal (men) and 3,000 kcal (women) were greater than the estimated energy requirements (~4,300 kcal) and intakes (~3,400 kcal) of grouped endurance athletes competing across various sports (6). Unpublished data, collected from the Canadian national men's training group, suggest that energy intake could reach ~7,000 kcal during midseason, high-volume training (~1,440 $min{\cdot}wk^{-1}$). Recently reported dietary intakes for elite rowers range from ~2,600 (women) to ~4,900 kcal (men) (Table 1).

To support moderate- to high-intensity training lasting a total of ≥3 $h{\cdot}d^{-1}$, 6 to 7 $d{\cdot}wk^{-1}$, current nutrition guidelines recommend daily carbohydrate intakes of approximately 6 to 12 grams per kilogram of body mass per day (g/kg BM/d)(13). Although there is controversy within the scientific literature regarding optimal carbohydrate intake targets for athletes, there is evidence highlighting beneficial training adaptations, improved power output (50), and prevention of performance deterioration and overreaching (1) when carbohydrate intake is optimized (*i.e.*, 8.5 to 10 vs 5 to 5.4 $g{\cdot}kg^{-1}$) for athletes undertaking daily, high-volume, high-intensity training (50). As rowers undertake training that is high volume, frequent (up to three sessions per day), and of varying intensities, it is likely that some portion of weekly training will naturally be performed with reduced muscle glycogen/low carbohydrate availability, potentially augmenting the adaptation response observed with "train-low" strategies (Table 2) (19).

The frequency of training sessions must be considered when determining individualized carbohydrate intake targets for daily glycogen restoration. Not only are there practical barriers to overcome (*e.g.*, appetite suppression, opportunity to consume food/fluid, etc.) but also there are physiological consequences, such as compromised glycogen resynthesis due to limited time between sessions (57) and resistance training-related skeletal muscle damage (21). It is acknowledged that rowers possess a high body and muscle mass; consequently, the uppermost end of the recommended ranges may overestimate the actual carbohydrate requirements.

Threshold and high-intensity training comprise a portion of rowing training programs, increasing in frequency during the specific preparation phase of the YTP (55,56). A rower's capacity to train at high intensity may be compromised if training is performed with low glycogen stores (52).

Table 2.
Description of training zones and potential nutritional strategies (Referenced in Table 3).

Training Characteristics	
Zone	*Training Intensity/Description*
Zone 1	Aerobic capacity, basic endurance, technical
Zone 2	Lactate threshold; development of aerobic capacity or anaerobic threshold
Zone 3	$\dot{V}O_{2max}$ or greater; anaerobic capacity, race-specific endurance
Potential Nutrition Strategies for Training Adaptation and Support	
Strategy	*Strategy Description*
High CHO-availability	Start session with replete glycogen stores to manage training load and prevent illness/overtraining
Low CHO-availability	Start session with little or no fuelling before training. Given generally high training volumes in the rowing YTP, this strategy is only recommended for experienced athletes who are not prone to illness/injury/overreaching. In addition, as many days contain two to three sessions, some training may naturally be completed with low carbohydrate stores.
CHO-During	Carbohydrate sport drink/food during session to manage high training load/volume
CHO mouth rinse	Carbohydrate mouth rinse used if low carbohydrate training or unable to consume carbohydrate during high-intensity training
Recovery	Adequate carbohydrate (1.2 $g{\cdot}kg^{-1}$) and protein recovery (0.3 to 0.4 $g{\cdot}kg^{-1}$) in preparation for the next session or next day
Protein	0.4 $g{\cdot}kg^{-1}$ in recovery from a strength session
Caffeine	~3 $mg{\cdot}kg^{-1}$ administered 30 to 60 min before or during fatiguing sessions
Supplement protocol practice	When determined to be advantageous, trial sodium bicarbonate, beetroot, and/or caffeine protocols during high-intensity or race pace sessions in consultation with the sports science and sports medicine team

$\dot{V}O_{2max}$, maximal oxygen uptake; CHO, carbohydrate; YTP, yearly training plan; g/kg BM, grams per kilogram of body mass.

Although individual carbohydrate tolerance must be considered, this potential compromise highlights the need for rowers to consume adequate carbohydrate in preparation for both high-intensity sessions and high-volume days. Carbohydrate, in the form of sports beverages, gels, or easily digested foods such as dates and bananas, ingested during higher intensity training provides a fueling opportunity contributing to overall carbohydrate requirements while simultaneously improving exercise performance (35). An important practical consideration when fueling before or during high-intensity workouts is gastric tolerance. If minimum fuel targets are unattainable or inappropriate during certain training sessions, carbohydrate mouth rinsing may be an effective strategy to mitigate performance decrements (34). Not only is carbohydrate an integral substrate to generate energy for muscular work, but also it supports neuromuscular metabolic processes and helps prevent cognitive exhaustion (37). This is of particular concern when undertaking heavy strength and conditioning and technical on-water sessions.

Timing of nutrient intake should be prioritized in relation to training sessions. When recovery time between sessions is limited, glycogen resynthesis is supported by carbohydrate intakes of 1.2 $g{\cdot}kg^{-1}$, within 60 min of training completion (57). Aggressive carbohydrate intake should be carried out on heavy training days (Table 3, Thursday), whereas a less prescriptive approach may be sufficient on lighter days (Table 3, Wednesday). It is important to determine the purpose of each session within the context of the rowers' training day/week and whether recovery goals are intended to restore glycogen deficits to optimize training capacity for an upcoming session, or to drive an adaptive response to the training stimulus (*e.g.*, promote metabolic adaptation by purposely withholding carbohydrate) (19). Given the large volume of endurance training combined with a substantial strength and power component, aggressive recovery is likely the most typical nutrition strategy within the preparation and competition phases of the rowing YTP (for review of strategies to optimize concurrent training, see ref. [27]). The consequences of unsupported training are considerable and may negatively impact training intensity and adaptation, as well as increase the risk of illness, injury, and overreaching (28).

Substantial emphasis is placed on resistance exercise, which is incorporated two to three times per week in rowing training programs. Resistance training increases the rate of skeletal muscle protein turnover, and in order for muscle to remodel and recover, a protein intake that results in positive protein balance is required (43). Recently refined protein recommendations suggest daily protein distribution of 0.4 $g{\cdot}kg^{-1}$ per meal to optimally stimulate muscle protein synthesis (MPS) and positive whole-body protein balance (4,43) (Table 4). Larger protein intakes, although oxidized at a higher rate, may further contribute to the considerable energy needs and meal satisfaction of the elite rower. This is of particular significance given rowers undertake multiple

Table 3.
Sample general preparation training week: high volume, moderate intensity (Refer to Table 2 for description of nutrition strategies).

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Morning session 1	**Row**	**Row**	**Row**	**Row**	**Row**	**Row**	**Row or cycle**
Morning zone/session focus	14-km technical: zone 1 aerobic	24-km basic endurance: zone 1 aerobic	18-km technical: zone 1 aerobic + zone 2 lactate threshold	28-km basic endurance: zone 1 aerobic	24-km basic endurance: zone 1 aerobic	18-km technical: zone 1 aerobic + zone 2 lactate threshold	28-km basic endurance: zone 1 aerobic
Nutrition before	Breakfast or low CHO-availability[a]	Breakfast: high CHO-availability	Breakfast: high CHO-availability	Breakfast: high CHO-availability	Breakfast: high CHO-availability	Breakfast: high CHO-availability	Breakfast: high CHO-availability
Nutrition during	CHO-During if there is difficulty maintaining BM, or CHO-Mouth rinse if low CHO-availability	CHO-During	CHO-During	CHO-During	CHO-During	CHO-During	CHO-During
Recovery nutrition	Recovery	Recovery	Recovery	Recovery	Recovery	Recovery	Recovery
Morning session 2	**Ergometer**	**Row**	**Off**	**Row**	**Row**	**Ergometer**	**Off**
Morning zone/session focus	Power session: zone 3 anaerobic capacity	14-km technical: zone 1 aerobic + zone 3 anaerobic capacity	Food in preparation for rowing session as appetite dictates	18-km zone 1 aerobic + zone 2 lactate threshold	14-km technical: zone 1 aerobic + zone 3 anaerobic capacity	Power session: zone 3 anaerobic capacity	Food in preparation for strength session as appetite dictates. Aim to include 0.4 $g \cdot kg^{-1}$ protein
Nutrition during	CHO-During or CHO-Mouth Rinse[b]	CHO-During or CHO-Mouth Rinse[b]		CHO-During	CHO-During or CHO-Mouth Rinse[b]	CHO-During or CHO-Mouth Rinse[b]	
Recovery nutrition	Recovery	Recovery		Recovery	Recovery	Recovery	
Afternoon session	**Row**	**Off**	**Row**	**Strength/core**	**Off**	**Row**	**Strength/core**
Afternoon zone/session focus	28-km basic endurance: zone 1 aerobic	—	18-km race endurance: zone 1 aerobic + zone 3 anaerobic capacity	Strength	—	18-km race endurance zone 1 aerobic + zone 3 anaerobic capacity	Strength
Nutrition during	CHO-During + caffeine	N/A	CHO-During or CHO mouth rinse + caffeine[b]	Water or CHO-During if there is difficulty maintaining BM	N/A	CHO-During or CHO mouth rinse + caffeine[b]	Water or CHO-During if there is difficulty maintaining BM
Recovery nutrition/dinner	Recovery	Recovery	Recovery	Protein	Recovery	Recovery	Protein

[a] Only recommended for experienced athletes who are not prone to illness/injury/overreaching.

[b] If there is difficulty feeding during high-intensity training; athletes also are recommended to consume a pre-bed snack including ~40 g of protein and 0.4 $g \cdot kg^{-1}$BM of carbohydrate at each meal due to high training volumes.

N/A, not applicable; CHO, carbohydrate; BM, body mass; g/kg BM, grams per kilogram of body mass.

Table 4.

Performance nutrition strategies at each training phase including potentially beneficial supplements to consider for elite rowers.

Nutrition Focus	General Preparation — High Volume and Endurance	Specific Preparation — Intensity	Taper	Competition	Regeneration
Daily intake (CHO, protein, and fat)	Maintain nutrition quality/ nutrient-density remain a priority intake • CHO intake 6 to 12 $g \cdot kg^{-1}$ per day • Protein intake of 0.4 $g \cdot kg^{-1}$ or more per meal • Fat intake as necessary to meet energy requirements • ~40 g of protein before bed • Focus on antioxidant-rich foods	Maintain high nutrition quality/nutrient-density remain a priority intakes • Higher CHO intake around key sessions • 1 to 2 low CHO intake sessions per week in experienced healthy athletes • Focus on antioxidant-rich foods	• Reduce CHO and fat intake focusing on nutrient-vs energy-dense foods and body composition management • Taper nutrition plan for any athlete who struggles to maintain appropriate weight/skinfold range	General preparation CHO intakes 1 to 2 d before competition	Forming or renewing performance nutrition habits • Reduce energy and CHO to meet nontraining requirements • Body composition management
Training Intakes	CHO-During most on-water and ergometer sessions when more than 1 session per day	CHO-During or CHO mouth rinse during key sessions.	Water during most training sessions	N/A	N/A
Recovery Nutrition	Focused recovery as soon as possible after each session • Recovery snack + follow-up meal if energy requirements are high • 0.3 g/kg BM of protein post-strength training	Focused recovery as soon as possible after each session • Recovery snack + follow-up meal if energy requirements are high • 0.3 g/kg BM of protein post-strength training • Practice competition recovery strategies	• Food as recovery • Mindful eating practice	Specific recovery • CHO + protein during immediate recovery, as practiced in specific preparation phase	Mindful eating practice
Supplements[a]	• Probiotics • Vitamin D[b] • Iron • Creatine • Caffeine for fatiguing sessions	• Probiotics • Vitamin D[b] • Iron • Beta-alanine • Caffeine for fatiguing sessions • Practice competition supplement strategies (BRJ/SB/caffeine)	• Probiotics • Vitamin D[b] • Iron	• Probiotics • Vitamin D[b] • Iron • Athlete-specific supplement protocol	• Iron
Notes	Risk of illness during high volume weeks	Risks of reduced appetite during high-intensity training	Body composition management and mindful eating strategies may be required	Athlete-specific intake strategies may be required for those who struggle to eat during competition	Remind athletes this is the best time to optimize iron stores

Medical/health supplements should only be prescribed in consultation with a sport physician to ensure the suitability of dose and protocol, and for ongoing monitoring. Performance supplements should only be incorporated under the guidance of a sports science and sports medicine team to ensure their safety, applicability, and effectiveness for each individual athlete.

[a] Ensure performance supplements (*e.g.*, creatine, HMB, etc.) are tested for banned substances and medical supplements are of pharmaceutical grade (*e.g.*, iron).

[b] October to April.

BRJ, beetroot juice; N/A, not applicable; CHO, carbohydrate; g/kg BM, grams per kilogram of body mass; HMB, beta-hydroxy beta-methylbutyrate; SB, sodium bicarbonate.

training sessions over consecutive days, and MPS remains elevated for 24 to 48 h after exercise (43).

Although the absolute protein quantity consumed appears to be the most important factor in MPS, the type and timing of protein intake also should be considered. Consumption of 0.4 g/kg of high biological value protein (milk, eggs, poultry, and meat) or ~3 g of leucine as soon as it is practical after key training sessions is recommended (43) (Table 4), and although milk stimulates an earlier response during the postprandial stage, both milk and beef ingestion equally increases postexercise MPS (12).

Finally, single resistance training sessions also can significantly impact glycogen stores in working muscles, with the greatest depletion occurring during moderate-load, high-repetition training such as hypertrophy training (45). Although it is not entirely clear that combined carbohydrate and protein ingestion will increase MPS, coingestion will help to achieve both adaptation and glycogen resynthesis, while contributing to the total energy needed to achieve and maintain a high lean BM. Due to increased mitochondrial protein turnover after endurance training (58), the same acute protein targets are recommended after aerobic exercise.

Fat intake recommendations should be based on overall YTP-dependent energy needs (*e.g.*, volume training vs taper vs competition). Although fat intake may help meet large energy requirements, a high-fat diet may displace carbohydrate and protein consumption, negatively impacting glycogen replenishment and tissue repair. In addition, a chronic high-fat, low-carbohydrate diet has been shown to impair glycogen use and high-intensity exercise ability, and should be considered with caution (19).

Maintaining Athlete Health

In a recent study, athletes who sustained less than two injuries or instances of illness were three times more likely to achieve performance success compared with those who sustained two or more per season (47). It is reasonable to suggest that a healthy, uninjured athlete with a strong immune system will cope with, and adapt to, the high training load associated with elite rowing training. In order to minimize training disruptions, poor performance, or withdrawal from competition, it is essential to proactively manage illness in rowers. In addition to sleep and hygiene, nutritional strategies should be among the primary approaches used to maintain athlete health, particularly during the high-volume preparation phase, in training camps, and in the lead up to (47) and during competitive events. Beyond adequate energy, high quality food consumption, and macronutrient and micronutrient intake, a few specific nutrients warrant discussion.

Vitamin D

Vitamin D, critical to bone health (42), is also being examined for its effect on immunity (30,44) and its potential impact on performance (22). The optimal vitamin D dosage and serum 25-hydroxy vitamin D (25(OH)D) levels considered necessary for human health are controversial and not well defined for athletes (22,44). Although the Institute of Medicine (IOM) considers serum 25(OH)D levels >50 $nmol \cdot L^{-1}$ to be adequate, it is increasingly accepted that immune, cardiovascular, and nervous system health may be superior with serum 25(OH)D concentrations >75 $nmol \cdot L^{-1}$ (see ref. [44] for review). During 4 months of winter training, athletes with optimal vitamin D status (>120 $nmol \cdot L^{-1}$) experienced reduced upper respiratory tract infection episodes compared with a vitamin D-deficient group (12 to 30 $nmol \cdot L^{-1}$), and athletes within the vitamin D-deficient group also experienced a 24% reduction in training volume (30). Further evidence supports vitamin D as a key nutrient in rib stress fracture prevention (a common occurrence in elite rowing (8.1% to 16.4%) [42]), whereas correlative data suggest that serum 25(OH)D3 >75 $nmol \cdot L^{-1}$ may be necessary for optimal muscle force recovery after damage (44). Athletes training at latitudes where dermal synthesis does not occur during winter are at risk of falling into deficiency (<50 $nmol \cdot L^{-1}$). It is therefore prudent to ensure rowers enter autumn with optimal (>100 $nmol \cdot L^{-1}$) vitamin D levels and that at-risk athletes be supplemented over the winter with 1,000 to 4,000 $IU \cdot d^{-1}$ (IOM, European Food Safety Authority) (44) to potentially limit illness, injury, and the conceivable negative impact on training load and performance (47).

Probiotics

Prolonged bouts of high-intensity exercise transiently disrupt several innate and acquired immune systems including leukocyte function (28), respiratory system, and gastrointestinal mucosa (46). Probiotics are believed to improve both digestive and immune health (46) because of their ability to modify gut microbiota, interact with gut-associated lymphoid tissue, and maintain gut wall integrity (46). Although not specific to rowers, several well-controlled athlete studies including endurance- and power-trained athletes indicate that daily probiotic ingestion results in fewer respiratory illness days and/or reduced upper respiratory symptom severity (46). Administration of *Lactobacillus* and *Bifidobacterium* spp. in daily doses of ~10^{10} live bacteria (28) is the most common protocol used to enhance immune function, with as little as 7 d required to elicit substantial changes in gut microbiota (46). In addition, recent findings suggest that immune cells may play a role in skeletal muscle adaptation and regeneration responses to exercise (25). With no evidence of harm, and where cost is not an issue, it may be practical to consider probiotic supplementation for a possible benefit to immunity and adaptation, before high-illness-risk periods such as intensified training, travel, and/or competition.

Iron

One of the most relevant nutrients to the health and optimal performance of a rower is iron (23). A functional component of hemoproteins, iron plays a central role in oxygen transport and storage, mitochondrial energy production, and eventual work output (11,48). Recent research suggests that increased iron availability also may stimulate MPS (11). Iron metabolism in endurance athletes such as rowers may be compromised for many reasons: poor intake, high energy expenditure, hemolysis, gastrointestinal symptoms, or sweat and urine losses (48). Possibly the most relevant reason is the postexercise rise in hepcidin, the iron regulatory hormone that is known to decrease iron absorption and recycling (5,51). The importance of hepcidin in iron status is increasingly demonstrated (5,11,51). For the athlete with compromised serum ferritin (<30 $\mu g \cdot L^{-1}$), increases in hepcidin may be overridden. However, the hepcidin elevation that occurs in athletes with ferritin >30 $\mu g \cdot L^{-1}$ will put those with borderline iron status (30 to 50 $\mu g \cdot L^{-1}$) at greater risk for iron deficiency (5). The high training loads combined with limited between-session recovery undertaken by elite rowers has been shown to negatively impact iron reserves. One study found that 27% of elite rowers/canoeists developed iron deficiency (<30 $\mu g \cdot L^{-1}$) by the end of a competitive season, and significantly, 14% began the following season with ongoing low ferritin (48). Altered daily training minutes, lower peak oxygen uptake, and impaired rowing performance (~21 s slower over 2 km) have been shown in iron-deficient, nonanemic rowers (44/165 athletes: ferritin <20 $\mu g \cdot L^{-1}$) when compared with those considered to have normal iron status (23). High carbohydrate intake during glycogen-depleting training sessions/phases is a probable strategy to attenuate post-exercise inflammation, subsequent hepcidin response, depleted iron stores, and possible negative performance outcomes (23).

Although the clinical threshold for iron deficiency is well defined, optimal levels for storage and therefore iron availability in athletic performance remains uncertain (11). Given the modest relationship between early-season iron status and performance (23) and the iron deterioration that can occur over a season (24), it would be ideal for the rower to maintain a ferritin status above 50 $\mu g \cdot L^{-1}$ (48). Rowers should optimize iron status through an intake of iron-containing foods, limiting or avoiding co-consumption of iron inhibitors (*i.e.*, tannins and calcium) as well as ingesting foods that enhance iron absorption (*i.e.*, meat/poultry/fish and vitamin C). When supplementation is required to restore or maintain iron stores, consultation with a sports physician and sports dietitian is essential for dosage and timing strategies to prevent possible iron toxicity (11) and circumvent the inhibitory effects of hepcidin (5,11,24,51). Clearly, iron status is critical to the health and performance of the elite level rower. Athlete monitoring, supplementation as appropriate, and nutrition education are key components to preventing poor iron status.

Performance Supplements to Enhance Training and Competitions

As previously mentioned, competitive 2,000-m rowing requires continuous, whole-body work, which maximally uses all energy systems (49). Several supplements that may augment training adaptations and/or those that might directly contribute to competitive success could be considered as part of a rower's training and competition nutrition plans.

Creatine

Creatine, a naturally occurring amino acid, effectively improves lean BM (10) and, specifically in elite rowers, endurance and anaerobic performance (18). Consumption with a recovery meal may augment the uptake of creatine in skeletal muscle (3), potentially enhancing its effectiveness (10). Rapid (20 $g \cdot d^{-1}$ for 5 d) and slow (3 $g \cdot d^{-1}$ for 28 d) loading protocols with creatine monohydrate appear equally effective in achieving supramaximal muscle creatine stores, allowing for protocol individualization based on athlete preference. Furthermore, long-term creatine supplementation appears to enhance overall training quality, leading to greater gains in strength and performance (9) and may therefore be an effective addition to rowers' supplementation strategy.

Caffeine

Caffeine is a naturally occurring central nervous system stimulant that appears to enhance voluntary muscle contraction and motivation, reducing fatigue, effort, and pain perception (14,19). Rowing ergometer performance over 2,000 m has been improved by 0.3% to 2.0% with various caffeine ingestion protocols ranging from 1.3 to 6.0 $mg \cdot kg^{-1}$ 10 to 90 min preexercise (14,17,49). The potential for negative side effects (disrupted sleep, elevated heartbeat, hand tremor, and edginess) (14) increases with caffeine intake >6 $mg \cdot kg^{-1}$ especially when used over several days of competition. As 3 $mg \cdot kg^{-1}$ has been demonstrated to improve 2,000-m elite rowing ergometer performance in the fed state, this would be a reasonable dose to begin trialing (17). Accounting for a rower's typical pre-race food and beverage caffeine intake when determining supplemental caffeine recommendations should help to avoid potential negative effects, and because of the variable caffeine content of food and beverages, utilization of products with known caffeine content will increase accurate and repeatable doses. Caffeine may also augment training capacity when used during deliberately fatiguing sessions (19), and advance coach/athlete planning to determine specific sessions for caffeine inclusion may be a valuable training approach. Although individual differences regarding the performance effect of caffeine may be due to genetics, individual tolerance, and/or fasted as opposed to postprandial caffeine intake (19), caffeine use is likely to enhance a rower's training or race nutrition strategy.

Beta-alanine

High-intensity training, 2,000-m ergometer time trials, and on-water competitive events cause hydrogen ion (H^+) accumulation and intramuscular acidosis that is associated with fatigue (39). Although muscle pH is well regulated by intracellular, extracellular, and dynamic buffering, nutritional strategies that reduce the negative impact of H^+ accumulation are likely to attenuate performance decline (32). Both beta-alanine and sodium bicarbonate (SB) may provide support in this area. Carnosine, a cytoplasmic dipeptide of beta-alanine and L-histidine, abundant within skeletal muscle, contributes to intracellular pH regulation (32,39). Beta-alanine supplementation (the limiting factor to carnosine synthesis) for ≥4 wk increases muscle carnosine concentration and was found *very likely* to benefit 2,000-m rowing performance (32). The absolute intramuscular carnosine increase is dependent upon total beta-alanine consumption rather than a daily supplemental dose, and for the desired 50% to 80% increase in muscle carnosine, a total of 230 g of beta-alanine (1.6 to 6.4 $g \cdot d^{-1}$), starting 1 to 2 months in advance of competition, is recommended (39,54). Coingestion with food is suggested to enhance skeletal muscle uptake (53) and to minimize or eliminate paresthesia, the only known and harmless side effect of beta-alanine supplementation (39).

Sodium Bicarbonate

Oral ingestion of SB, a natural extracellular buffer, enhances blood buffering capacity during high-intensity exercise (31). Although rowing-specific research is equivocal (14,16), two recent studies in trained rowers demonstrated a *very likely* beneficial effect over a 2,000-m rowing ergometer test compared with placebo (31,32). The addition of acute SB to beta-alanine supplementation appears to confer a slightly greater benefit to 2,000-m performance than either supplementation regimen in isolation (32). An acute dose of 0.3 g of SB per kilogram coingested with a carbohydrate-rich meal (~1.5 $g \cdot kg^{-1}$) consumed over 30 to 60 min, 120 to 180 min before the start of exercise will induce substantial blood alkalosis while minimizing the potential for negative gastrointestinal side effects (15). Given the risk of significant negative gastrointestinal consequences before performance, SB loading should be trialed extensively before being incorporated into a rower's race-day nutrition strategy.

Beetroot Juice

The incorporation of beetroot juice as a competition strategy requires midseason testing and protocol development (7,33). Beetroot juice, a natural source of inorganic nitrates, increases plasma nitrate and nitrite and subsequently nitric oxide (NO) bioavailability (7,33). NO mediates many performance-related functions, and it has been hypothesized that competitive rowing is ideal for nitrate supplementation (33). In fact, beetroot juice supplementation was demonstrated to improve the final three of six supramaximal 500-m rowing efforts (7) as well as possibly improve in a 2,000-m ergometer time trial in elite rowers (33). Although supplemental nitrate effects may be blunted in highly trained individuals (33), elite rowers may nonetheless benefit because, in theory, large muscle mass-related oxygen limitations during high workloads, coupled with a maximal oxygen uptake of up to 6.8 $mL \cdot kg^{-1} \cdot min^{-1}$ (56), suggests that elite rowers have not maximized NO synthetic capabilities (36). In addition, rowers with higher basal nitrate levels may require a larger dose for an ergogenic effect. As such, studies reporting no beneficial effects of beetroot juice supplementation have identified nitrate responders (36) as well as a possibly beneficial performance effect with a higher nitrate dose (140 mL of beetroot, 8.4 mmol nitrate, vs 70 mL of beetroot, 4.2 mmol nitrate) consumed before a 2,000-m rowing ergometer time trial (33).

Supplements Requiring Further Investigation

Antioxidants and Tart Cherry Concentrate

Evidence suggests that tart cherry concentrate, with its high anti-inflammatory and anti-oxidative capacity may help endurance athletes recover from and prevent performance decrements during repeated strenuous exercise sessions (20). Although there may be promising initial reports, concerns that antioxidants may blunt physiological training adaptations have been raised. Tart cherry concentrate may be an option however when optimal recovery (*e.g.*, during competition), as opposed to adaptation, is the goal. During the training season, current literature suggests that athletes should focus on vegetable and fruit intake to obtain antioxidant components (polyphenols, etc.) required to support health and recovery from training (19).

Beta-hydroxy Beta-methylbutyrate

Beta-hydroxy beta-methylbutyrate (HMB) is a leucine metabolite that stimulates MPS and attenuates muscle protein breakdown. Recently, 12 wk of supplementation with HMB in trained rowers (resistance, high intensity, and endurance training) demonstrated a reduction in fat mass and an increase in both aerobic capacity and anaerobic peak power (26). Additional research is needed to determine whether these effects are repeatable and related to enhanced rowing performance.

Beyond establishing if a supplement has scientific evidence supporting its use in rowing, several additional factors must be considered.

- Supplementation, whether for health or performance reasons, should be considered on an individual athlete basis and must be undertaken in consultation with the athlete and coach, and under the guidance of the sports science and sports medicine team.
- Are the supplements banned by the World Anti-Doping Agency (http://list.wada-ama.org/)?
- Are there negative side effects or interactions when consumed alone or in combination with other products?
- Is the supplement easy to administer and incorporate into training/competition nutrition plans?

In terms of practical application, each supplement or combination of supplements should be trialed as often as required within the YTP to establish trusted protocols, especially considering individual responses (41) and readiness to undertake supplementation. Marginal gains from ergogenic supplements do not aggregate, and combination supplement studies in elite athletes show performance improvements similar to single supplement studies (29). Consider that the magnitude of effect for both ergogenic aids and belief effect (placebo) is approximately 1% to 3%, with the ingestion of two placebo pills providing a better result than one (29). One carefully chosen supplement might therefore be adequate to maximally enhance performance; however, trialing two or even three supplements could be considered, both from a potentially beneficial psychological effect and by increasing the odds of eliciting an enhanced performance effect.

Conclusion

Rowers require highly developed aerobic and anaerobic systems as well as a significant level of strength and power. Given the demanding nature of rowing training loads, and considering the complexity of an individual's response to training and nutrition interventions, individualized and flexible performance nutrition planning is essential. It can be assumed that both aggressive nutrition strategies and optimal supplementation are necessary to support the health and performance of open-weight rowers. This foundation will likely assist in preventing illness and injury, as well as maximizing adaptation and recovery. Various supplements known to enhance energy systems that potentially improve rowing performance should also be investigated and considered for strategic use within the daily training environment and/or competition settings.

A notable finding of this brief review is the paucity of recent, relevant published literature, specifically focused on performance nutrition and elite-level rowers. Research on endurance- and power-trained athletes has general applicability; however, it may not provide the necessary minutiae to support rowing-specific nutrition guidelines. Further research on sports nutrition and supplementation specific to the elite rower is encouraged to further develop knowledge in this area.

The authors declare no conflict of interest and do not have any financial disclosures.

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