Beta-alanine supplementation and improvement of performance in swimming and water polo: a systematic review

Pedro Salvadori,[1] Matheus Caputo,[1] Vitor Mansur,[1] Luciana Pietro[2*]

Abstract

Introduction: Beta-alanine is a non-essential amino acid that is naturally produced by the human body and used by many athletes and practitioners of physical activity to reduce muscle fatigue and to increase performance in high performance exercises. As a precursor of intramuscular carnosine, it has been shown to reduce the hydrogen ions that cause muscle fatigue during exercise in sports such as swimming and water polo. Objective: To evaluate various beta-alanine supplementation protocols in swimmers and water polo players and their effects on performance. Methodology: This study is a systematic review of various beta-alanine supplementation protocols used in exercises involving water polo and high-performance swimming, from searches on the Pubmed, SCIELO and RBNE platforms. Articles in English and Portuguese were included, which were evaluated on the basis of methods and parameters specific to swimming and water polo. Results: The review found that beta-alanine supplementation protocols varied according to the studies and their objectives. However, beta-alanine supplementation was shown to be effective in improving times, reducing blood lactate and increasing strength. Conclusion: Supplementation with beta-alanine generates a possible beneficial effect on swimmers and water polo players by fostering improvements in time, reduction of blood lactate and strength, all of which can positively influence the results of competitions and championships. The best protocols are those that administered a dose greater than or equal to 4.8g per day for, at least, four weeks.

1. Departamento de Nutrição, Universidade Paulista. Campinas, SP, Brazil.
2. Departamento de Biomedicina, Universidade Paulista. Campinas, SP, Brazil.

*Correspondence address:
E-mail: lucianapietro1@gmail.com
ORCID: https://orcid.org/0000-0002-8511-2196

BJHBS, Rio de Janeiro, 2023;22(2):117-125
DOI: 10.12957/bjhbs.2023.80048
Received on 13/05/2023. Approved on 18/07/2023.

Keywords: Beta-alanine; Supplement; Carnosine; Swimming; Water polo.

Introduction

Beta-alanine supplementation has been the focus of studies in sports because its function, in conjunction with histidine, is to synthesize increased amounts of intramuscular carnosine. Studies show that increases in carnosine can occur through beta-alanine supplementation, which conclusion has been confirmed by a robust body of evidence produced since 2006, when the first study attesting to this fact in humans was published.[1]

Carnosine is a dipeptide found within skeletal muscle, whose function within the muscles is to buffer hydrogen ions, which are potentiators of muscle stress and acidosis, thus causing increased muscle fatigue during physical activity.[2]

According to studies, the properties of carnosine are related to its buffering effect, by acting directly in controlling muscle acidosis generated by hydrogen ions. Carnosine is formed by combining non-proteogenic amino acid beta-alanine with amino acid l-histidine (catalyzed by the enzyme carnosine synthetase) to form the dipeptide β-alanyl-L-histidine (i.e. carnosine). Once bound with beta-alanine, l-histidine is diverted from protein synthesis mechanisms, allowing high concentrations of this dipeptide to accumulate in skeletal muscle. Other factors that influence the amount of carnosine found include age, sex, type of muscle fiber, diet, and variables determining the concentrations of this compound.[2-4]

Administration of beta-alanine supplementation in powder form is associated with a rapid increase in the plasma amount at approximately 30-45 min after ingestion, regardless of the dose administered, which may be 10, 20, or 40mg/kg body weight. However, doses higher than 10mg/kg body weight are not well accepted. They generate discomfort in users, who complain of increased paresthesia, a neuropathy affecting the areas near the face, neck, shoulders, chest, and buttocks, usually in this exact order. Since paresthesia does not present health risks, this sensation can be considered a side effect rather than an adverse one.[5,6]

According to Matos,[3] the main characteristic of the effect of beta-alanine supplementation is a decrease in metabolic acidity, which stimulates an increase in carnosine concentrations and acts to improve the ability to perform acidotic efforts. This occurs due to the buffering effect of the hydrogen ions and their potentiation with histidine of a higher concentration of intramuscular carnosine, and has prompted athletes to increasingly seek its use. Its ergogenic function has been shown to be more effective within periods of high intensity and short duration, thus, studies have shown that its range lies between 30 seconds to 10 minutes.[3,7]

According to Maté-Muñoz,[8] the ingestion of high dosages of beta-alanine supplementation has always been correlated with a tingling sensation, manifesting itself commonly as irritability in the areas of the face, arms and hands. This effect happens because beta-alanine activates MrgprD receptors in primary sensory neurons, triggering an itching/tingling sensation that can last from 10 to 20 minutes, or even more than 60 minutes when taken in large doses. For this reason, the substance should be administered in several doses throughout the day in order to avoid adverse effects caused by the high dosages normally used when single doses are administered.

Beta-alanine supplementation is most recommended in exercises where the greatest use of energy and the main substrate comes from ATP, which occurs through anaerobic glycolysis, resulting in an increased release of lactic acid. The sports that most use the anaerobic glycolytic pathway include cycling, swimming, canoeing, water polo etc.[9]

Therefore, this study seeks to evaluate the effect of beta-alanine consumption on performance in water sports, and to describe the supplementation protocols used in conjunction with swimming and water polo.

Methodology

A systematic review was conducted using the Pubmed (Medline), Revista Brasileira de Nutrição Esportiva, and SCIELO databases. The descriptors used in the search and confirmed by the Descriptors in Health Sciences (DeCS) were beta-alanine, swimming, water polo, carnosine and supplementation, always in a combination with any of the five descriptors, using their equivalents in the English language.

The search was filtered for studies since 2012, and the inclusion criteria selected were original articles that address the theme of nutritional supplementation of beta-alanine in water sports, with a focus on swimming and water polo. Systematic review articles, meta-analyses, or those with possible conflicts of interest were excluded from reading and, consequently, from the review.

The inclusion criteria for the studies were the reading of titles and abstracts to exclude articles that did not study beta-alanine supplementation as a primary endpoint and that were available free of charge in the databases, while the exclusion criteria were the studies that did not fit the subject or were outside the field of nutrition.

The study was divided into three phases. The first followed the search criteria and the reading of abstracts and titles for analysis of the inclusion and exclusion criteria. The second comprised the full reading of articles for analysis of their effectiveness and descriptive contribution to the present study. The third phase was the development of the present article, its results and conclusions, in accordance with the criteria used in the two previous phases.

Results

In the 8 studies analyzed, a total of 164 male and female elite and amateur swimmers participated, 84% of which were men.

Most of the studies were conducted in a double-blind placebo-controlled fashion with the exception of the study by Mero,[10] in which both participants and researchers were aware that all subjects were consuming beta-alanine over a 4-week period (non-blinded). Two studies, by Painelli[11] and Mero[10] used the consumption of beta-alanine in conjunction with sodium bicarbonate as co-supplementation. In the study by Painelli,[11] two supplementation protocols were used, one solely with beta-alanine and one in conjunction with sodium bicarbonate, the latter being excluded from this survey. Mero,[10] meanwhile, analyzed only the joint supplementation of beta-alanine with sodium bicarbonate, so these results were maintained in our survey (Table 1).

The studies were separated into two groups according to their approach to diet and supplementation. The studies by Brisola,[12,13] Claus,[14] Norberto[15] and Mero[10] controlled the diet of the participants, while the studies by Chung[6] and Painelli[11] did not include any form of dietary control.

In the studies by Brisola,[12,13,16] the method adopted was the non-use of supplementation for at least three months prior to the study, as well the absence of dietary controls. Differently, Claus[14] maintained the supplementation of whey and maltodextrin to which the athletes were already accustomed, but stipulated at the beginning of the study that the participants must not have used beta-alanine for at least six months before the beginning of the studies, and creatine for at least three months. However, no dietary controls were implemented.

Table 1. Characteristics of the studies evaluated.

Study	Participants	Exercise performed	Intervention (Supplementation)	Interval (days)	Result
Chung[6]	41 elite male and female swimmers	100m and 200m freestyle	4,8g for the first 28 days and 3.2g for the last 42 days	70	Improved race time in the first 28 days of supplementation and reduced blood lactate in the last 42 days
Mero[10]	13 male swimmers	2 sprints of 100m freestyle	4,8g per day	28	No change in performance
Painelli[11]	16 male and female swimmers	100m and 200m freestyle	3,2g for the first 7 days and 6.4g for the last 28 days	35	Improvement in race time (100m e 200m)
Brisola[12]	22 male swimmers	Sprint1 + 30min Swim + Sprint2	4,8g for the first 10 days and 6.4g for the last 18 days	28	Sprint1 time improvement
Brisola[13]	22 male swimmers	Tied swim (30s) + Free swim 200m + Barre Jump (30s)	4,8g for the first 10 days and 6.4 for the last 18 days	28	Improved strength in tied swimming (30s) and 200m freestyle swimming
Claus[14]	15 young male water polo players	RSA Test (Sprint and Throw) + Tied swim (30s) alternated with jump + Free swim 200m	6,4g per day	42	Improved time and throwing power in the RSA test; Improved strength in the jump; Improved performance in the 200m freestyle swim
Brisola[16]	22 male swimmers	Gradual effort in Tied swim + Total effort in Tied swim (3min)	4,8g for the first 10 days and 6.4 for the last 18 days	28	Improvement in strength associated with Vo2 max consumption
Norberto[15]	13 male and female swimmers	400m freestyle + Tied swim session (30s)	4,8g per day	42	No change in performance

Legend: NRSA: training in the ability of repeated sprints; VO2 max: maximum volume of oxygen.
Source: The authors (2023).

The study by Norberto[15] recruited participants who were not chronic users of nutritional supplements or anti-inflammatory medications. They received instructions not to consume alcohol, caffeine, and energy drinks for at least 12 hours before each measurement. Mero[10] did not stipulate any control over the participants' eating habits, controlling only supplementation and allowing the use of protein and carbohydrate based supplements, while prohibiting creatine and caffeine.

Differently, Chung[6] chose not to control the diet of the participants, only controlling for creatine, caffeine and sodium bicarbonate supplementation during the study. Meanwhile, Painelli[11] did not measure any diet and supplementation parameters of the participants.

The studies used different types of exercises and tests based on swimming and water polo training: (a) Chung[6] and Painelli[11] used the 100- and 200-meter freestyle, (b) Mero[10] used only two 100-meter freestyle sprints, (c) Claus[14] followed a water polo practice simulation training protocol consisting of eight 50-meter sprints followed by a maximum sprint from the edge to the middle of the pool where the athlete shoots the ball into the goal, thus determining time and strength parameters, (d) Norberto[15] analyzed 400-meter freestyle sessions followed by a 30-second tethered swim, observing time and strength patterns, while (e) Brisola and colleagues[12,13,16] performed similar exercises in their three studies, changing only the frequency, time performed and order of exercise, such that in Brisola[13] two repeated sprints interspersed by 30-minute swims were performed; Brisola[12] used a 30-second tethered swim followed by a 200-meter free swim and repeated jumps on the bar (in the pool) in a 30-second interval, and Brisola[16] used a gradual effort tethered swim for a period of 3 minutes.

Some of the studies were divided into competition phases. In Chung[6] the tests were conducted between two competitions (national and international) over a 10-week supplementation interval. The studies conducted by Brisola[12,13,16] started in the general preparatory phase of the season and ended in the competitive phase of each year. In contrast, the study conducted by Claus[14] lasted for six weeks, which were divided into a general preparation phase, specific training and pre-competition training during the last two weeks of training. Only one of the studies, by Norberto,[15] did not specify the period in which the protocol was performed.

Participants in five[6,11-13,16] of the eight studies received differing doses during the beta-alanine supplementation period, such that most received higher dosages in the initial days to increase intramuscular carnosine loading (saturation). In the remaining three studies, by Mero[10], Claus[14] and Norberto[15], the supplementation was administered in a uniform manner, without any increases or decreases in dosage over time.

In the protocol conducted by Chung,[6] a 4.8g/day dose was administered during the first 28 days and a maintenance dose of 3.2g/day was provided during the last 42 days. In the protocol used by Painelli,[11] a lower dose was administered during the first seven days (3.2g/day) and a higher dose during the last 28 days (6.4g/day). All three studies conducted by Brisola[12-13,16] followed the same supplementation protocol: a starting dose of 4.8g/day during the first 10 days and a final dose of 6.4g/day during the last 18 days.

The studies conducted by Mero[10] and Norberto[15] used a dosage of 4.8g/day throughout the supplementation period, while the study by Claus[14] used 6.4g/day.

The supplementation of 4.8g/day used by Mero[10] and Norberto[15] showed no effect on the performance of the participants, even using different training protocols and different study times. Claus[14] observed improvements in time and strength of participants in the RSA test (sprint and ball throw), 30-second tethered swim alternated with a bar jump and 200m freestyle swim.

Chung[6] observed an improvement in race times during the first 28 days of supplementation (beta-alanine saturation phase) and a reduction in blood lactate during the last 42 days (maintenance phase) (Figure 1).

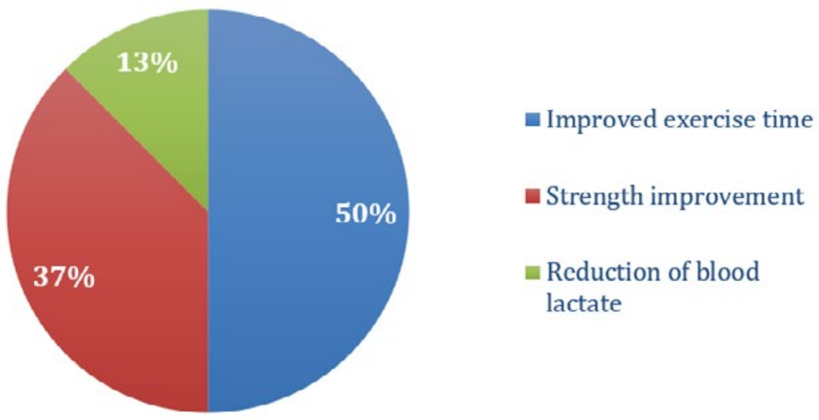

Figure 1. Results of the performance changes in the studies
Source: The authors (2023)

Discussion

Beta-alanine and the potential ergogenic effects of chronic supplementation in high-intensity exercises have become a topic of great interest within the sports community,[17] stimulating several studies that seek to measure the effectiveness of such supplementation in various high-performance sports. However, many contradictions can be found in the findings of these studies, which should be reviewed and analyzed in depth, specifically within each sport modality. Research in aquatic sports still shows contradictions and a lack of evidence of positive effects, when compared with other sports that stimulate physical exertion at the same levels as swimming and water polo.

In contrast to swimming and water polo, cycling is the modality that most stands out in studies and findings on this topic. Apparently, the long 10km time trial races that last more than 1 hour are not influenced by β-alanine supplementation, which can be explained by the fact that the predominant glycolytic pathway is aerobic.[7,18-19] However, in long-duration cycling races, high-intensity shots occur during attempts to overtake other cyclists, which increases the use of the anaerobic pathway and, consequently, muscle acidosis. At this point, when sprints of an average of 30 seconds were performed in this type of test, Van Thienen[19] showed that β-alanine supplementation can improve performance in sprints.

In the case of this study, analysis of the use of supplementation in water sports found that the average age of the 164 participants analyzed was 19 years, which can be explained by the fact that this age is associated with a higher level of intramuscular carnosine concentration, since this dipeptide can become depleted in older people.[2]

Analysis of the results showed that 50% of the studies found improvements in exercise time after receiving beta-alanine supplementation, while 37% reported gains in strength and 13% reported reduced blood lactate. The findings of the main studies on β-alanine supplementation on swimming performance are still divergent and even contradictory, although some studies indicate that this strategy is very likely to be effective in improving performance in 100m and 200m races, since these distances require a high production of lactate by the anaerobic pathway.[9]

Taking into account the parameters used in the studies, the training methods, time and intensity control, a strong impact can be observed on performance in swimming competitions in 100m and 200m races, since, similarly to creatine, beta-alanine does not promote weight gain, but allows for an increase in high intensity efforts.[20-21]

When conducting their study, Painelli and colleagues[11] found an improvement in swimming times in the 100m and 200m freestyle (1.4-2.1% improvement), as did Chung.[6] However, Chung,[6] even with a longer period of supplementation, was unable to find conclusive evidence of any improvement in performance after the fourth week of beta-alanine administration, observing only a decrease in lactate during the last 6 weeks, which had no ergogenic impact on the athletes.

Another factor that was also found not to contribute to changes in performance were doses lower than 4.8g in a short period of beta-alanine supplementation. This lack of change in performance is explained by Harris,[22] who demonstrates that achieving significant increases in intramuscular carnosine requires supplementation over a period longer than a minimum of four weeks with doses of 6.4g of beta-alanine, in order to promote increases of up to 64% in intramuscular carnosine content. The same conclusion is reached by Mero and colleagues[10] who showed that their study should have included higher doses of beta-alanine over a longer period of time in order to observe expected positive changes in performance, reaching the same conclusions as Baguet[2], who also emphasizes the need for a longer period of supplementation with higher doses, in order to achieve greater increases in intramuscular carnosine.

The results observed included evidence of a heightened ergogenic effect in studies that involved the administration of higher doses of beta-alanine, either in terms of duration or quantity, until the end of the protocol. Although no measurements of intramuscular carnosine levels were taken, the studies have as a general parameter that beta-alanine supplementation promotes an increase of approximately 50% in carnosine levels, which is confirmed by the study of Hill,[23] in which the administration of 4 to 6.4g/day of beta-alanine was shown to increase muscle carnosine concentrations by 59% after 4 weeks and 80% after 10 weeks. In their study, Chung and colleagues[6] discuss the dosages used, which were based on studies by Stellingwerff and by Harris that demonstrated the viability of performance enhancement with beta-alanine administration to increase muscle carnosine stores.[1,22]

However, six of the eight studies presented unclear results (probable beneficial effect at competitive levels) in which improvements in strength and time were small, but significant. This may have an ergogenic effect at a competitive level, where a few seconds and a stronger throw can have positive effects on the final result in a competition, as argued by Claus.[14]

Another aspect of the use of beta-alanine is its use as a supplement in conjunction with sodium bicarbonate. According to a study by Mero[10] the purpose of this association would be enhanced supplementation when both substances are used together. However, no relevant results have been observed from this association.

One of the limiting factors in the studies was metabolic adaptive interference arising from training and competitions during the protocols used. These activities can reduce blood lactate, and consequently improve the parameters used to identify the ergogenic effect of beta-alanine, as cited by Norberto.[15] Another limiting factor observed among all the studies was that the samples of participants are quite small for the purposes of analyzing performance in a competitive sport with various variables that determine ergogenic effects.

In addition, the studies analyzed were unable to measure intramuscular carnosine, a dipeptide that contributes to the buffering of hydrogen ions and acts to decrease muscle acidosis. This limiting factor occurs because measurement is not feasible, since it would require interventions such as biopsies for the measurement of intramuscular carnosine, which, according to Chung,[6] would be unrealistic to be performed on elite athletes while they were preparing for competition.

Given these limiting factors, one of the parameters used to find performance improvement was the decrease and control of lactate, as exemplified by Kontic,[24] since anaerobic lactate endurance is a significant predictor of offensive and defensive agility for water polo, as confirmed by almost all authors. The exception is Chung and colleagues[18] who did not describe the improvement in blood lactate as having a stronger relationship with training-generated adaptions than simple beta-alanine supplementation, despite finding a reduction of the organic compound in their results. On the other hand, other studies that found reductions in lactate showed that this decrease was due to adaptations generated by training and not by the supplementation itself.

Conclusion

The results presented in this study confirm a possible beneficial effect of beta-alanine on the performance of swimmers and water polo players, through a decrease in muscle acidosis and, consequently, fatigue. When associated with physical exercise and not used in isolation; however, the protocol applied has significant influence on the results obtained.

The best beta-alanine supplementation protocols analyzed consisted of the administration of doses greater than or equal to 4.8g per day for a least a 4-week period, since these studies used doses of up to 6.4g per day without an initial saturation period. Only one study did not show improved performance with this protocol pattern.

One can conclude that the improved performance associated with the use of beta-alanine is presented in such parameters of aquatic sports as time in the 100m and 200m freestyle, sprints, and throwing force. The supplementation of beta-alanine should occur every day, regardless of the time of day it is administered. However, in order to avoid the side effect of paresthesia, the daily dose should be split into smaller dosages administered at 2-hour intervals.

For better results, in future studies, we suggest that the intramuscular carnosine of the swimmers and athletes be measured in conjunction with the supplementation of beta-alanine during the protocol used.

References

1. Stellingwerff, T, Anwander H, Egger A, et al. Effect of two beta-alanine dosing protocols on muscle carnosine synthesis and washout. Amino Acids. 2012 jun;42(6): 2461-72. doi: 10.1007/s00726-011-1054-4.
2. Baguet A, Everaert I, Achten E, et al. The influence of sex, age and heritability on human skeletal muscle carnosine content. Amino Acids. 2012;43(1):13-20. doi: 10.1007/s00726-011-1197-3.
3. Matos VAF, de Albuquerque Filho NJB, Rebouças GM, et al. A carnosina diminui os efeitos da acidose muscular durante o exercício. RBNE 2015;9:164-71.
4. Spelnikov D, Harris RC. A kinetic model of carnosine synthesis in human skeletal muscle. Amino Acids. 2019;51(1):115-121. doi: 10.1007/s00726-018-2646-z
5. Saunders B, Franchi M, de Oliveira LF, et al. 24-Week beta-alanine ingestion does not affect muscle taurine or clinical blood parameters in healthy males. Eur J Nutr. 2020;59(1):57-65. doi: 10.1007/s00394-018-1881-0.
6. Chung W, Shaw G, Anderson ME, et al. Effect of 10 week beta-alanine supplementation on competition and training performance in elite swimmers. Nutrients. 2012;4(10):1441-53. doi: 10.3390/nu4101441.
7. Bellinger PM. beta-Alanine supplementation for athletic performance: an update. J Strength Cond Res. 2014 Jun;28(6):1751-70. DOI: 10.1519/JSC.0000000000000327.
8. M Maté-Muñoz JL, Lougedo JH, Garnacho-Castaño MV, et al. Effects of β-alanine supplementation during a 5-week strength training program: a randomized, controlled study. Journal of the International Society of Sports Nutrition. 2018 Apr 25;15(1). doi: 10.1186/s12970-018-0224-0.
9. Campos EZ, Kalva-Filho CA, Gobbi RB, et al. Anaerobic Contribution Determined in Swimming Distances: Relation

with Performance. Frontiers in Physiology [Internet]. 2017 Oct 10;8. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5641383/. doi: 10.3389/fphys.2017.00755.

10. Mero AA, Hirvonen P, Saarela J, et al. Effect of sodium bicarbonate and beta-alanine supplementation on maximal sprint swimming. Journal of the International Society of Sports Nutrition. 2013 Nov 11;10(1). doi: 10.1186/1550-2783-10-52.

11. de Salles Painelli V, Roschel H, de Jesus F, et al. The ergogenic effect of beta-alanine combined with sodium bicarbonate on high-intensity swimming performance. Applied Physiology, Nutrition, and Metabolism. 2013 May;38(5):525–32. doi: 10.1139/apnm-2012-0286.

12. Brisola GMP, Artioli GG, Papoti M, et al. Effects of Four Weeks of β-Alanine Supplementation on Repeated Sprint Ability in Water Polo Players. Ardigò LP, editor. PLOS ONE. 2016 Dec 8;11(12):e0167968. doi: 10.1371/journal.pone.0167968.

13. Brisola GMP, Milioni F, Papoti M, et al. Effects of 4 Weeks of β-Alanine Supplementation on Swim-Performance Parameters in Water Polo Players. International Journal of Sports Physiology and Performance [Internet]. 2017 Aug 1 [cited 2021 Mar 9];12(7):943–50. Available from: https://pubmed.ncbi.nlm.nih.gov/27967270/.

14. Claus GM, Redkva PE, Brisola GMP, et al. Beta-Alanine Supplementation Improves Throwing Velocities in Repeated Sprint Ability and 200-m Swimming Performance in Young Water Polo Players. Pediatric Exercise Science. 2017 May;29(2):203–12. doi: 10.1123/pes.2016-0176

15. Norberto MS, Barbieri RA, Bertucci DR, et al. Beta-alanine supplementation effects on metabolic contribution and swimming performance. J Int Soc Sports Nutr 2020;17(1):40. doi: 10.1186/s12970-020-00365-6.

16. Brisola GMP, Redkva PE, Pessoa Filho DM, et al. Effects of 4 weeks of beta-alanine supplementation on aerobic fitness in water polo players. PLoS One. 2018;13 (10): e0205129. doi: 10.1371/journal.pone.0205129.

17. Blancquaert L, Everaert I, Derave W. Beta-alanine supplementation, muscle carnosine and exercise performance. Curr Opin Clin Nutr Metab Care. 2015;18(1):63-70. doi: 10.1097/MCO.0000000000000127.

18. Chung W, Baguet A, Bex T, et al. Doubling of muscle carnosine concentration does not improve laboratory 1-hr cycling time-trial performance. Int J Sport Nutr Exerc Metab. 2014;24(3):315-24. doi: 10.1123/ijsnem.2013-0125.

19. Van Thienen R, Van Proeyen K,Vanden Eynde B, et al. Beta-alanine improves sprint performance in endurance cycling. Med Sci Sports Exerc. 2009; 41(4):898-903. doi: 10.1249/MSS.0b013e31818db708.

20. Kendrick IP, Harris RC, Kim HJ, et al. The effects of 10 weeks of resistance training combined with beta-alanine supplementation on whole body strength, force production, muscular endurance and body composition. Amino Acids. 2008; 34(4): 547-54. DOI: 10.1007/s00726-007-0008-3.

21. Kresta JY, Oliver JM, Jagim AR, et al. Effects of 28 days of beta-alanine and creatine supplementation on muscle carnosine, body composition and exercise performance in recreationally active females. J Int Soc Sports Nutr. 2014;11(1):55. doi: 10.1186/s12970-014-0055-6.

22. Harris RC, Tallon MJ, Dunnett M, et al. The absorption of orally supplied beta-alanine and its effect on muscle carnosine synthesis in human vastus lateralis. Amino Acids. 2006;30(3):279-89. doi: 10.1007/s00726-006-0299-9.

23. Hill CA, Harris RC, Kim HJ, et al. Influence of beta-alanine supplementation on skeletal muscle carnosine concentrations and high intensity cycling capacity. Amino Acids. 2007;32(2):225-33. doi: 10.1007/s00726-006-0364-4.

24. Kontic D, Zenic N, Uljevic O, et al. Evidencing the association between swimming capacities and performance indicators in water polo: a multiple regression study. J Sports Med Phys Fitness. 2017;57(6):734-43. doi: 10.23736/S0022-4707.16.06361-1.