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Glutamine Accelerates Post-Exercise Recovery of Arms Power, Leg Power, and Smash Velocity at 48 Hours for Non-Elite Badminton Athletes

La glutamina acelera la recuperación posterior al ejercicio de la potencia de los brazos, las piernas y la velocidad del smash en 48 horas para atletas de bádminton que no son de élite

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Abstract. Badminton is a sport that is characterized by long-lasting muscle contractions in continuous smash movements which lead to fatigue and glutamine can potentially reduce the incidence of muscle fatigue. The aim of the study is to investigate glutamine affecting post-exercise recovery in non-elite badminton athletes. It was a randomized group pre-test and post-test design. Twenty male students were involved and divided into 2 groups: The placebo (Plac) group was only given instruction for jumping smash activities and mineral water, while the glutamine (Glut) group was jumping smash activities and mineral water containing glutamine. The jumping smash activities were carried out in 10 sets with 20 repetitions with a rest period of 30 seconds per set. Glutamine was given 3 times after 1 hour of jumping smash activities, 24 hours, and 48 hours with a dose of 0.4 grams/KgBW. There were significant differences in the vertical jump, leg power, arm power, and smash velocity in pre-post-2 between the Placebo and Glutamine groups with $p<0.05$. Meanwhile, no difference was observed in the vertical jump, leg power, arm power, and smash velocity ($p>0.05$) between the Placebo and Glutamine groups 72 hours after the jumping smash activities (post 3). The administration of glutamine at a dose of 0.4 gram/Kg BW given three times post-jumping smash (eccentric) exercise can accelerate the 48-hour post-exercise recovery of vertical jump, arm power, leg power, and smash velocity. Badminton athletes who play matches daily are expected to consume glutamine to speed up recovery.

Keywords: Glutamine; physical exercise; badminton; non-elite athletes

Resumen. El bádminton es un deporte que se caracteriza por contracciones musculares duraderas en movimientos continuos que provocan fatiga y la glutamina puede reducir potencialmente la incidencia de fatiga muscular. El objetivo del estudio es investigar la glutamina que afecta la recuperación post-ejercicio en atletas de bádminton que no son de élite. Fue un diseño de prueba previa y posterior a grupos aleatorios. Participaron veinte estudiantes varones y se dividieron en 2 grupos: el grupo de placebo (Plac) solo recibió instrucción para actividades de saltos smash y agua mineral, mientras que el grupo de glutamina (Glut) recibió actividades de saltos smash y agua mineral que contenía glutamina. Las actividades de salto smash se realizaron en 10 series con 20 repeticiones con un período de descanso de 30 segundos por serie. Se administró glutamina 3 veces después de 1 hora de actividades de salto, 24 horas y 48 horas con una dosis de 0.4 gramos/kg de peso corporal. Hubo diferencias significativas en el salto vertical, la potencia de las piernas, la potencia de los brazos y la velocidad del smash en pre-post-2 entre los grupos de Placebo y Glutamina con $p<0.05$. Mientras tanto, no se observaron diferencias en el salto vertical, la potencia de las piernas, la potencia de los brazos y la velocidad del smash ($p>0.05$) entre los grupos Placebo y Gluta-mine 72 horas después de las actividades de salto smash (después de 3). La administración de glutamina en una dosis de 0.4 gramos/kg de peso corporal administrada tres veces después del ejercicio smash (excéntrico) del salto puede acelerar la recuperación del salto vertical, la potencia de los brazos, la potencia de las piernas y la velocidad del smash 48 horas después del ejercicio. Se espera que los atletas de bádminton que juegan partidos a diario consuman glutamina para acelerar la recuperación.

Palabras clave: Glutamina; ejercicio físico; bádminton; atletas no elite

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Introduction

Badminton is a sport characterized by various intensive movements and specific movement patterns consisting of rapid acceleration, deceleration, and various explosive movements with changes in direction over short distances (Huang, Liang and Ren, 2019). Badminton is a sport known for its intense and short bursts of activity, primarily relying on the anaerobic system. Players typically have a maximum heart rate of 190.5 beats per minute, with an average of 173.5 beats per minute during matches lasting over 30 minutes. The average duration of a score is 6.4 seconds, followed by a 12.9 second break between shifts (Medina Corrales *et al.*, 2021). Badminton players have to display maximum speed, agility, flexibility, endurance, and strength. It is a combination of an anaerobic and aerobic system in short rallies with high intensity as well as maintaining efforts for the recovery process (Phomsoupha, Berger and Laffaye, 2018). In addition, badminton also requires rapid changes in direction, jumps, attacks on the net and arm movements with various body postures (Matsunaga and Kaneoka, 2018). Among the many strokes in badminton, the jumping smash is an indispensable hit to get points to win the game. The dominant stroke in doubles matches is the forehand jumping smash accounting for 1/5 of the number of attacks (Park *et al.*, 2017).

A jumping smash is a continuous series of coordinated movements of the whole body. Movement coordination in jumping smashes is influenced by skeletal muscles, which can stimulate somatic motor neurons and induce activity in all body segments (Gomez *et al.*, 2019), including changes in position or motor segments (Wagner *et al.*, 2012). Players who perform jumping smash require maximum strength in the muscles of the legs, arms, abdomen, and hands supported by physical components for complex movements (Hirashima *et al.*, 2002). There is an isotonic contraction of the rectus femoris concentric, hamstring eccentric, and gastrocnemius concentric in the jumping smash movement. This contraction will rise until the jump movement is carried out with a stretch reflex motion to send neuromuscular impulses to the spinal cord to be able to make a good jump. When the jump movement is performed, there is an isotonic contraction of the rectus femoris eccentric, concentric hamstring, and eccentric gastrocnemius, and the rectus femoris and gastrocnemius muscles transmitted mechanical energy widely from the proximal joint to the distal part at the end of the phase. Meanwhile, the hamstring muscles send some mechanical energy to return the hip line of motion (Markovic and Jaric, 2006). Long-lasting muscle contractions in continuous smash movements during the tournament can reduce energy in the body, causing fatigue and a decrease in muscle strength and speed that delay the command of stimulation (Le Mansec *et al.*, 2018). Lack of motion control and slowing down are indications of fatigue conditions (Aragonés *et al.*, 2018).

Muscle fatigue is generally defined as a reduction in a person's ability to produce sufficient power due to limitations in the central nervous system in transmitting impulses to muscle fibers (Gomez *et al.*, 2020). Muscle fatigue is characterized as a reduction in the capacity to generate muscular force or energy at a satisfactory level during a training session. Muscle fatigue can arise from various factors, including alterations in pH, temperature, and the buildup of metabolic byproducts in the bloodstream. Some of these byproducts are adenosine diphosphate (ADP), adenosine monophosphate (AMP), inosine monophosphates (IMP), inorganic phosphate groups (Pi), and ammonia. They are mostly made when adenosine triphosphate (ATP) breaks down. The disruption of Ca2+ ion homeostasis and the changing roles of different ions in intracellular and extracellular environments (like K+, Na+, Cl-, and Mg2+) caused active muscles to have lower energy substrates during the training period (Cervantes Hernández, Hernandez Nájera and Carrasco Legleu, 2022). Muscle fatigue is classified into central and peripheral fatigue. Peripheral fatigue occurs in muscles and involves specific movements that cause dysfunction in the neuromuscular region, contraction mechanisms, etc. Meanwhile, central fatigue associated with the upper part of the brain triggers alpha motor neurons and affects the whole body (Deka *et al.*, 2017). Therefore, in peripheral fatigue, the command of movement does not change or rise, but it drops in the center, causing a decrease in muscle tension (Phomsoupha, Berger and Laffaye, 2018). Fatigue is one of the factors that interfere with neuromuscular control (Granata, Slota, and Wilson, 2004). Fatigue in the muscles and joints of the lower extremities, i.e., the ankle, tends to alter the stability of the muscle strength and reduce its ability to produce a balanced and stable response (Huang *et al.*, 2023).

Muscle damage which results in the rise of oxidative stress is the cause of muscle fatigue and can be minimized by giving glutamine (Coqueiro, Rogero and Tirapegui, 2019). The administration of glutamine resulted in a decrease in muscle damage indicators (plasma CK and LDH) and inflammation indicators (plasma IL-1β and TNF-α), while increasing the levels of anti-inflammatory and cytoprotective markers (plasma IL-6, IL-10, and muscle HSP70) (Raizel *et al.*, 2016). Plasma CK concentrations exhibited a decrease 24 hours after exercise while using a glutamine supplement as compared to carbohydrate supplementation (Coqueiro, Rogero and Tirapegui, 2019). Although there were improvements in some indicators, the injection of glutamine and alanine did not enhance performance as assessed by a maximum carrying capacity test (Leite *et al.*, 2016). Several mechanisms might explain this protective effect of glutamine. The amino acid is absorbed through sodium-dependent transport, increasing the intracellular sodium ion concentration and water retention, leading to the rising hydration of cells and their resistance to lesions. Glutamine also plays an important immuno-modulatory role, increasing the synthesis of anti-inflammatory and cytoprotective factors, such as interleukin 10 (IL-10) and heat-shock protein (HSP) (Raizel *et al.*, 2016). In addition, evidence suggests that glutamine is an essential donor of glutamate for synthesizing glutathione which is the most crucial non-enzymatic antioxidant in cells, indicating the antioxidant effect of glutamine (Leite *et al.*, 2016) by which increased oxidative stress can cause fatigue is still unclear. Glutamine can potentially reduce the incidence of muscle fatigue, especially in badminton athletes. The aim of the study is to investigate glutamine affecting post-exercise recovery of arm power, leg power, and smash velocity at non-elite badminton athletes.

Material and Methods

Study Design

This study was a true-experimental with a randomized group pre-test and post-test design. Twenty male students who are members of the badminton club at the Universitas Negeri Surabaya were involved and selected using a purposive sampling technique. They are 18-22 years old with normal body mass index (BMI) and have at least three years of experience practicing in a badminton club. They would be excluded from the study if they had cardiovascular disease, experienced muscle injury during the last six months, or refused to participate. The study subjects were selected using a purposive sampling technique and divided into 2 groups randomly, namely the control group that received placebo (Plac; n=10) and the treatment group that received glutamine (Glut; n=10). All study protocol was ethically clear by Faculty of Dental Medicine Health Research Ethical Clearance Commission of Universitas Airlangga with number of 582/HRECC.FODM/VIII/2022. Informed consent was obtained from each respondent involved in the study.

Treatment Procedure

Both groups (Plac and Glut) did a jumping smash with 10 repetitions, 10 sets, and 30 seconds of rest between sets. The Placebo (Plac) group was given 250 mineral water without glutamine at 1 hour, 24 hours, and 48 hours after the jumping smashes. In comparison, the glutamine (Glut) group was given 250 mineral water filled with glutamine at the dose of 0.4 gram/KgBW 1 hour, 24 hours, and 48 hours after the jumping smashes (Rusdiawan and Taufikkurrachman, 2020). While participating in this research, all subjects were ensured not to consume supplements other than those provided by the research team.

Instrument and Data collection

Arm power, leg power, and smash velocity were measured as the indicators of accelerated recovery since after continuous jumping smash activities, the strength and speed of the muscle contraction weakens due to muscle fatigue (Ooi *et al.*, 2009; Le Mansec *et al.*, 2018). Data were collected four times, i.e., before the jumping smash activity (pre-test), 24 hours (post-test 1), 48 hours (post-test 2), and 72 hours (post-test 3) following the jumping smash activities. The arm power variable was measured using a 3-kg medicine ball, while leg power was measured by performing a vertical jump test using the Takei Vertical Jump Meter. The results of vertical jumps can describe the ability of leg power (Orr *et al.*, 2016). The test was carried out three times for each, and the best data were taken. The results of the jump height (h) in cm which was then converted into power in Watts using the formula:

$$P = \frac{m \times g \times h}{t}$$

Annotation: P = Power (Watt); m = mass (kg); g = gravity (9,8 m/s); h = jump height (m); t = time (s) (Wismanadi *et al.*, 2020).

Smash velocity was measured using a Bushnell 101922 radar gun manufactured in Germany with units of km/hour (Rusdiana *et al.*, 2020).

Statistical analysis

The data were analyzed to determine the mean value and differences before and after treatment using one-way ANOVA and differences between groups using an independent sample t-test. The data of the study were analyzed by using the SPSS version 23 for windows. The entire data were normally distributed regarding the results of the normality test using the one Kolmogorov Smirnov test ($p > 0.05$). All data are presented with mean ± SD. All data uses a significance level of 5%.

Results

The results of data on the characteristics of the research respondents are shown in Table 1. Respondents were 19 years old on average and have practiced around six years of badminton. The mean weight and height of the respondents were 66.18 and 167.24, respectively, and had normal BMI (Table 1).

The average jumping smash before and after (pre-post-1) measurement decreased significantly, yet the results of post-test 2 and post-test 3 obtained varied results (Figure 2). An independent sample t-test was conducted to test the differences between the groups from several data collection times (pre-post1-post2-post3). The two groups experienced an increase in the value of vertical jump, leg power, arm power, and smash velocity, which was not different. The administration of glutamine has an effect after 48 hours but no effect after 72 hours of jumping smash activities.

There were significant differences in the vertical jump, leg power, arm power, and smash velocity in pre-post-2 between the Placebo and Glutamine groups with p-value ($p<0.05$), as seen in Table 3. These data showed that the administration of glutamine 48 hours after the jumping smash activities significantly affects the recovery of vertical jump, leg power, arm power, and smash velocity. Meanwhile, there was no difference in the vertical jump, leg power, arm power, and smash velocity ($p>0.05$) between the Placebo and Glutamine groups 72 hours after the jumping smash activity (post-test 3).

Description: Data were collected four times, i.e., before the jumping smash activity (pre-test), 24 hours (post-test 1), 48 hours (post-test 2), and 72 hours (post-test 3) following the jumping smash activities.

Table 2 and Figure 1 show that the jumping smash has reduced the ability to vertical jump, leg power, arm power, and smash velocity after 24 hours of doing it (post-test 1). However, after 48 hours, this ability began to increase (post-test 2). At 72 hours, these abilities resemble the initial conditions before doing a jumping smash (post-test 3) (Table 3).

Table 1.
Characteristics of research subjects

Variable	Mean±SD
Age (yrs)	19.55 ± 1.36
Height (cm)	167.24 ± 3.55
Weight (kg)	66.18 ± 2.70
BMI (kg/m^2)	23.67 ± 0.96
Practice experience (yrs)	6.20 ± 0.89

Table 2.
Variable measurement by groups

Variables	Phase	Normality test p (sig)	Mean ± SD	
			Plac (n=10)	Glut (n=10)
Vertical jump (cm)	Pre-test	0.200	63.80±5.37	63.40±4.20
	Post-test 1	0.200	58.40±5.05	57.40±4.74
	Post-test 2	0.200	59.00±5.37	60.9±4.61
	Post-test 3	0.127	62.600±5.13	63.10±4.84
Legs power (Watt)	Pre-test	0.200	982.41±50.36	1029.49±54.74
	Post-test 1	0.200	865.72±49.18	933.03±65.89
	Post-test 2	0.200	874.03±61.15	959.74±51.99
	Post-test 3	0.200	964.49±89.79	1030.72±62.81
Arm power (cm)	Pre-test	0.560	425±44.78	423±41.65
	Post-test 1	0.200	404±40.40	404.5±42.65
	Post-test 2	0.200	399.5±34.36	417±44.23
	Post-test 3	0.144	423.5±42.50	424±4.31
Smash velocity (km/h)	Pre-test	0.180	156.64±7.93	157.39±5.74
	Post-test 1	0.200	140.45±7.53	142.37±3.90
	Post-test 2	0.200	143.07±8.52	148.43±5.82
	Post-test 3	0.157	150.13±7.72	155.35±4.31

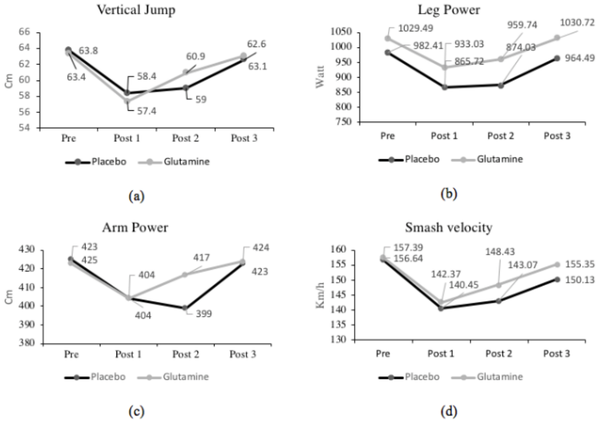

Figure 1. (a) vertical jump test result; (b) Leg power test result; (c) Arm power test result; (d) Smash velocity test result.

Table 3.
Effect of jumping smash and giving glutamine to variables

Variable			p (sig)	
			Plac (n=10)	Glut (n=10)
Vertical jump	Pre-test	Post-test 1	0.000*	0.000*
		Post-test 2	0.000*	0.000*
		Post-test 3	0.578	0.867
	Post-test 1	Post-test 2	0.140	0.001*
		Post-test 3	0.050*	0.015*
	Post-test 2	Post-test 3	0.106	0.277
Legs power (watt)	Pre-test	Post-test 1	0.000*	0.000*
		Post-test 2	0.000*	0.000*
		Post-test 3	0.498	0.947
	Post-test 1	Post-test 2	0.233	0.009*
		Post-test 3	0.006*	0.003*
	Post-test 2	Post-test 3	0.018*	0.007*
Arm power (cm)	Pre-test	Post-test 1	0.002*	0.002*
		Post-test 2	0.004*	0.193
		Post-test 3	0.656	0.735
	Post-test 1	Post-test 2	0.262	0.024*
		Post-test 3	0.003*	0.003*
	Post-test 2	Post-test 3	0.006*	0.116
Smash velocity	Pre-test	Post-test 1	0.000*	0.000*
		Post-test 2	0.000*	0.000*
		Post-test 3	0.003*	0.082*
	Post-test 1	Post-test 2	0.061*	0.002*
		Post-test 3	0.000*	0.000*
	Post-test 2	Post-test 3	0.000*	0.002*

*significant difference at $p<0.05$

The analysis of the one-way ANOVA between performance before (pre-test) and after (post-test) treatment showed a significant decrease in performance after 24 hours of practicing the jumping smash in the Placebo and Glutamine groups, so did the results 48 hours and 72 hours after the jumping smash activities. The Placebo and Glutamine groups also experienced an increase, but several participants in Placebo groups had an insignificant increase. To find out the difference in the effect of the two groups, an independent sample t-test was performed (Table 4).

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The independent sample t-test analysis results showed significant differences in the post-jumping smash performance of vertical jump, arm power, leg power, and smash velocity at 48 hours (Table 4). This means that glutamine administration can accelerate performance recovery 48 hours after exercise.

Table 4.
Differences values of variables by the groups

Variable		Mean±SD		p (sig)
		Plac (N=10)	Glut (N=10)	
Vertical jump	Δpre-post 1	5.40±0.97	6±1.76	0.358
	Δpre-post 2	4.80±1.23	2.5±0.85	0.000*
	Δpre-post 3	1.20±6.58	0.30±5.50	0.744
	Δpost 1- Post 2	-0.60±1.17	-3.50±2.22	0.002*
	Δpost 1- Post 3	-4.20±5.88	-5.70±6.04	0.581
	Δpost 2-Post 3	-3.60±6.33	-2.20±6.01	0.618
Legs power (watt)	Δpre-post 1	116.69±32.40	96.46±40.39	0.233
	Δpre-post 2	108.38±46.33	69.75±26.43	0.034*
	Δpre-post 3	17.92±80.23	-1.23±56.96	0.546
	Δpost1-post 2	-8.32±20.58	-26.71±25.73	0.095
	Δpost1-post 3	-98.78±86.69	-97.69±75.68	0.977
	Δpost2-post 3	-90.46±98.63	-70.98±64.34	0.607
Arm power (cm)	Δpre-post 1	21.00±15.06	18.5±13.55	0.701
	Δpre-post 2	25.5±20.61	6.00±13.50	0.022*
	Δpre-post 3	1.5±10.29	-1.00±9.07	0.571
	Δpost1-post 2	4.50±11.89	-12.5±14.58	0.010*
	Δpost1-post 3	-19.5±15.54	-19.5±14.99	1.000
	Δpost2-post 3	-24±20.92	-7.00±12.74	0.042*
Smash velocity	Δpre-post 1	15.19±5.01	15.01±4.92	1.000
	Δpre-post 2	12.58±3.79	8.96±2.40	0.021*
	Δpre-post 3	5.51±4.60	2.04±3.16	0.068
	Δpost1-post 2	-2.62±3.77	-6.06±4.66	0.081
	Δpost1-post 3	-9.68±2.65	-12.97±4.86	0.075
	Δpost2-post 3	-7.07±3.37	-6.92±4.77	1.000

*significant difference at $p<0.05$

Discussion

Glutamine was used in the study as a supplement which is believed to be able to accelerate the recovery process of the athletes after performing the exercise. Data analysis found that the ability of vertical jump, leg power, arm power, and smash velocity of the participants decreased after jumping smash activities (pre-post1). The declining ability can be caused by fatigue, a condition of a person's inability to maintain external power and strength which causes disturbances in physical and mental performance. More specifically, muscle fatigue is peripheral fatigue that biochemical changes that occur in skeletal muscle cells (Finsterer, 2012). Blood glutamine and glutamine/glutamate ratios decrease due to strenuous exercise. There was a decrease in glutamine concentrations in plasma, muscle, and liver in experimental animals that experienced complex fatigue due to being forced to swim (Jin *et al.*, 2009). The previous study also found that athletes with chronic fatigue for several weeks showed a decrease in blood glutamine to less than 450 mol/L and an increased prevalence of infection. Increasing protein intake, such as lean meat, fish, cheese, and milk which are rich in glutamine, is known to increase glutamine levels in the blood and in turn, will improve the performance of the athletes (Castell, Poortmans and Newsholme, 1996).

Fatigue can reduce the performance of badminton athletes during jumping smashes, causing slow shuttlecock speed and changes in body segment movement (Rusdiana *et al.*, 2020). Jumping smash in badminton requires maximum power and complex movements with the support of leg muscle power, abdominal muscle strength, and arm and hand muscle strength (Hirashima *et al.*, 2002). The hand used to hit continually leads to muscle contraction vigorously during exercise or competition, and it will reduce energy sources in the body and lead to fatigue (Ooi *et al.*, 2009). Reduced energy decreases the strength and speed of muscle contraction, which can cause the stimulation of commands from the brain to the muscles to be slower (Le Mansec *et al.*, 2018). Uncontrolled conditions and slower movement can indicate that a person's muscle condition is becoming increasingly tired (Aragonés *et al.*, 2018). The fact is that badminton players need explosive movements, including sprints, lunges, jump smashes, and rapid changes of direction (Hader, Palazzi and Buchheit, 2015)(Walklate *et al.*, 2009), driven mainly by the feet, hence the primary source of fatigue. In addition, neuromuscular involvement occurs in the lower limbs (Huang *et al.*, 2019). In line with this, research has proven that fatigue also harms badminton athletes when hitting forehand smashes(Zhang, 2020). Badminton, which is a high-intensity sport, will cause sports fatigue, which will not only affect performance but can also increase the risk of injury (Xu *et al.*, 2018).There was a significant result in the data of the post-2 group obtained 48 hours after the athlete did the jumping smash activity and was given a glutamine drink two times (ΔPre-post2). This result showed that glutamine could accelerate the recovery of vertical jump, leg power, arm power, and smash velocity after jumping smash activity. This finding follows the research conducted by Wismanadi et al. (2021) that the administration of glutamine supplementation of 0.4 grams/kg BW for three days can increase the vertical jump at 48 hours after the exercise. Glutamine can delay fatigue through various mechanisms. Firstly, it is a highly abundant amino acid that plays a significant role in the energy production processes of the body, such as the Krebs cycle and gluconeogenesis (Bassini-Cameron *et al.*, 2008). Secondly, glutamine directly stimulates the synthesis of glycogen, a form of stored energy in the body, by activating glycogen synthase (Coqueiro, Rogero and Tirapegui, 2019). Thirdly, glutamine acts as a carrier for ammonia, preventing its harmful accumulation in the body (Coqueiro, Rogero and Tirapegui, 2019). Lastly, glutamine is associated with reducing muscle damage and indirectly acts as an antioxidant by promoting the synthesis of glutathione, a protective molecule. These are just a few examples of the many ways in which glutamine can delay fatigue (Leite *et al.*, 2016; Raizel *et al.*, 2016). Research has shown that supplementing with glutamine during human exercise can successfully decrease tissue and organ damage, enhance glycogen synthesis, provide nutritional support for the immune system, and prevent infection (American Dietetic Association *et al.*, 2009). Creatine kinase isozyme MM (CK-MM) was employed as a biomarker to assess muscle injury in terms of muscle metabolism characteristics. The concentration of CK-MM in the serum normally rises during physical exercise (Banfi *et al.*, 2012; Koch, Pereira and Machado, 2014). During physical activity, there is a localized deficiency of oxygen in the skeletal muscles, leading to the buildup of metabolites and an elevation in free radicals. This results in the impairment of cell membranes and an augmented permeability. Currently, CK-MM within muscle cells crosses the cell membrane and enters the bloodstream, following the same mechanism that causes an elevation of CK-MM levels after intense exercise (Koch, Pereira and Machado, 2014; Moghadam-Kia, Oddis and Aggarwal, 2016).

Studies examining the effect of glutamine administration on basketball athletes showed that glutamine can help reduce exercise-induced muscle damage in sports disciplines with dominant eccentric action (Córdova-Martínez *et al.*, 2021). Glutamine, given as a dietary supplement, can also improve the performance of running athletes. The 30-meter runners who are given a particular diet program and consume glutamine three times a day, namely in the morning, after exercise, and before going to bed, each of which contains 10 grams of glutamine, can increase the speed. Administered glutamine as a supplement positively affects the development and improvement of muscle strength (Mohammed, Sadown and Humaidi, 2019). Glutamine supplementation in five adults aged 22-41 years showed that periods of intense exercise were associated with decreased plasma glutamine concentrations. Muscle glutamine levels are related to the rate of protein synthesis (Coqueiro, Rogero and Tirapegui, 2019). In the vasculature, low plasma glutamine concentrations also occur in several clinical situations, such as burns, major surgery, long-term starvation, and sepsis. Therefore, glutamine needs to be increased to regulate the activity of the immune system and stimulate cell division involved in the muscle repair process. In this case, glutamine serves as fuel for the immune cells and repair processes (Córdova-Martínez *et al.*, 2021). During and after exercise training, increased lactic acid and accumulation of fatty acids and acetoacetic acid lead to acidosis. Exercise can lower blood pH from 7.4 to 6.9 (Vilmi *et al.*, 2016). This acidosis will increase glutamine absorption to provide ammonia genesis (Piattoly and Welsch, 2004). Diets high in protein, such as glutamine, can reduce metabolic acidosis so that acid base balance is better maintained. A balanced acid-base will keep the performance of the athletes more stable as it delays fatigue (Chycki *et al.*, 2018; Baranauskas *et al.*, 2020). The use of glutamine is more advantageous following, rather than preceding, intense physical exertion (Lu *et al.*, 2023).

A study by van Hall et al. (2000) found that supplementing glutamine alone or mixed with carbohydrates did not affect in resynthesizing protein after exercise. This difference in results may be due to the different study protocols involved in the study results (van

Hall *et al.*, 2000). In the long term, glutamine supplementation cannot improve performance during interval training, but the administration of glutamine and carbohydrates is more efficient in preventing a decrease in anaerobic strength and improving performance than giving glutamine alone. However, other studies have not shown the same results (Krieger, Crowe and Blank, 2004). Glutamine administration had an effect at 48 hours because the decrease in strength and speed due to eccentric exercise began to decrease significantly at 48 and 72 hours (Street, Byrne and Eston, 2011). In addition, the pain was reduced in the elbow flexor at 24 and 48 hours after eccentric exercise after being given 3.6 g of L-glutamine before, immediately, and after four days after eccentric exercise (Legault, Bagnall and Kimmerly, 2015). Thus, the administration of glutamine can accelerate muscle recovery by allowing physiological concentrations of glutamine maintained during exercise training.

Conclusion

The administration of glutamine at a dose of 0.4 gram/Kg BW given three times post-jumping smash (eccentric) exercise can accelerate the recovery of post-exercise vertical jump, arm power, leg power, and smash velocity at 48 hours after the exercise. Badminton athletes who play matches daily are expected to consume glutamine to speed up recovery so the force of their arms and legs remains stable. Thereby, their performance can maintain in the next match.

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