SC-2

운동중 대사적 피로 개선을 위한 Ergogenic Aids의 역할

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서 론

운동시 피로(Fatigue) 발생은 운동수행(Performance)에 영향을 주기 때문에 많은 연구자들은 운동시 발생하는 피로의 원인을 밝혀내어 운동수행에 기여하고자 많은 연구를 수행하고 있다. 그러나, 운동시 발생하는 피로를 연구하는데 있어서 가장 중요한 문제점은 피로를 야기시키는 요인들이 매우 복잡하다는 것과 요인들 간에 상호 연계성을 갖고 있다는 것이다. 일반적으로, 운동시 피로 발생 원인의 복잡성은 그 원인들이 심리적, 생리적, 생화학적 요인들을 다양하게 포함하고 있다는 것이라 할 수 있다. 그러므로, 운동시 발생하는 피로의 원인을 살펴보기 위해서는 몇 가지 제한적인 요소들 중에서 특히, 대상자의 근 섬유 형태와 트레이닝 상태, 근 수축의 수의성 여부 및 운동강도와 운동지속 시간들을 고려해야 할 것이다. 본 원고에서는 이들 중, 주로 운동강도와 운동지속 시간에 따라 초래되는 대사적 피로 요인들에 대해서 살펴보고 이들을 효과적으로 억제 및 지연시키는 방안으로 Ergogenic Aids의 역할을 고찰해 보도록 한다.

본 론

피로의 개념

운동시 발생하는 피로는 결국 운동 수행과 관련하여 생각해야 하며, 일반적으로 "주어진 운동강도에서 지속적인 근 수축으로 power-output을 유지할 수 없는 상태"로 정의할 수 있다.

운동시 피로 발생 가능 부위

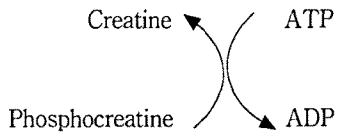
운동시 피로 발생과 관련하여 가능성 있는 부위는 의지력(will to win)에 영향을 미칠 수 있는 뇌에서부터 활동근의 cross-bridge 까지 다양하다.

Psyche/Mood
▽
Brain
▽ ← motivationm
Spinal cord
▽
Peripheral nerve
▽
Neuromuscular junction
▽ ← neuromuscular transmission
Muscle fiber membrane
▽ ← muscle action potential
Transverse tubular system
▽ ← excitation
Ca^{++} release
▽ ← activation/energy supply
Actin-myosin interaction
▽
Cross-bridge tension
▽
Power-output

운동시 대사적 피로 발생 요인

운동시 대사적 피로 발생 요인들은 안정시보다 활성화된 활동근(working muscle)의 수축·이완 과정에서 요구되는 에너지 동원 system(ATP-PC, Glycolysis, Oxidation; Edward L Fox, 1979)에서의 기질 제한성과 이들 대사과정에서 생성된 부산물(by-products; proton, NH_4^+ 등)이 있으며, 이외에도 체 수분의 손실과 전해질(Na^+ 등)의 불균형 등이 가능하다.

1) The Depletion of Phosphocreatine(in muscle)



Lipmann Rx.(1941)

cf) ATP storage : 5umol/g · muscle
CP storage : 20umol/g · muscle

- Ex. intensity : supramaximal
- Ex. duration : <7~8 sec.

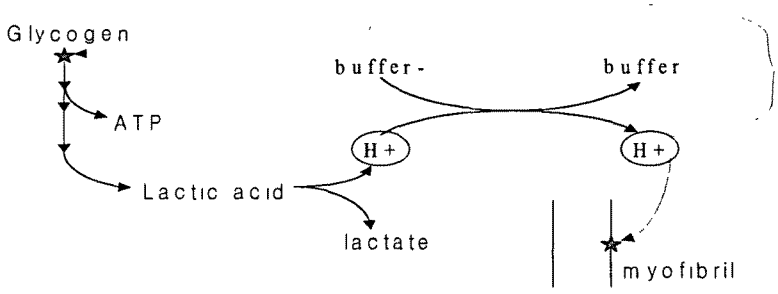
※ Ergogenic Aids : Creatine supplementation
⇒ · ↑ 5~7% of power-output
presumably due to enhanced phosphocreatine levels
· body mass of about 1~2kg(mostly as LBM)

2) The Accumulation of Proton(in muscle)
: by Anaerobic Glycolysis

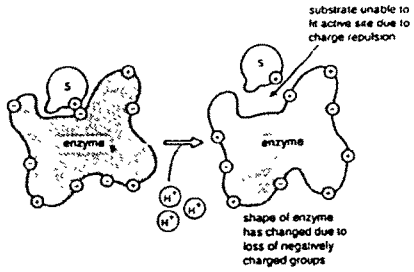
Glycogen(Glucose) → 2Lactic acid → $2Lactate^- + H^+$
(cf, Sprinter finished in "a sea of lactate ion plus protons not of lactic acid")

- Ex. intensity : ↑80% of VO_2max
- Ex. duration : 30~90 sec.

▷ How the increase in proton concentration leads to fatigue is unclear but there are a number of different suggestions
ⓐ ↑ Ca^{++}-binding capacity of the sarcoplasmic reticulum
ⓑ ↓ myofibrillar ATPase activity
ⓒ ↓ 6-phosphofructokinase activity



ⓓ change of the shape of enzyme



: especially for an enzyme catalysing a critical reaction in energy generation in muscle or a component of a myofibril involved in cross-bridge formation

ⓔ ↑HR(for cardiovascular system)

↑H^+ : $H^+ + HCO_3^- \rightarrow H_2CO_3 \rightarrow H_2O + CO_2(\uparrow PCO_2)$

→ peripheral chemoreceptor(carotid body on carotid artery)

→ central chemoreceptor(in the medulla)

→ respiratory center

→ respiratory muscle

→ ↑ventilation [↑2ℓ · min^{-1}(VE)/1㎜Hg PCO_2]

→ peripheral vessels dilatation

→ ↓venous return

→ ↓stroke volume

→ ↑heart rate(to maintain cardiac output)

※ Ergogenic Aids(mostly using a buffering action; alkalinizing agents)

· Sodium hydrogencarbonate(formerly known as sodium bicarbonate) supple.

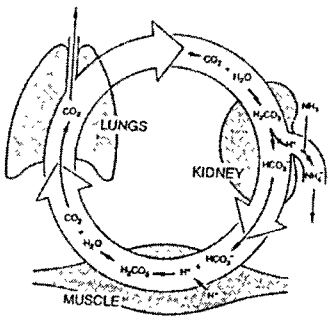
- Claim : chief buffering system of the human body
- Facts : nausea, bloating, intestinal cramping, diarrhea at dose of more than 0.3g/kg

[cf, (sodium) citrate(0.3~0.5g/kg는

· gastric distress 없이 sodium bicarbonate와 유사한 이점 초래

· PFK의 allosteric inhibitor : a potential role of enhancing body loss with exercise

$HCO_3^- + H^+ \rightarrow H_2CO_3 \rightarrow H_2O + CO_2$(to air through the lungs)



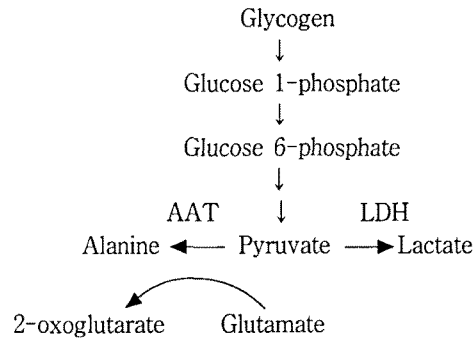
: Most of the hydrogencarbonate ion(HCO_3^-) is made in the kidney and combines with protons from muscle to form carbon dioxide, which is excreted from the lungs

· Lactate and Polylactate supple.

$Lactate^- + H^+ \rightarrow$ Lactic acid(to urine/sweat/acetyl-CoA/liver glucose)

- Claim : · ↑additional enzyme activity to remove lactate
  · a fuel for energy production or gluconeogenesis(Cori cycle)
- Facts : 0.75% 이상의 polylactate supple.는 gastrointestinal distress 초래

· Glutamate supple.



* Metabolic fates of pyruvate in anaerobic pathway
AAT : Alanine amonotransferase, LDH Lactate dehydrogenase

- Claim : ↓ lactic acid conc. during and after exercise
- Facts : · ↓ permeability of plasma membrane ⇒ diarrhea
  · neuro-toxic(chinese restaurant syndrom) ⇒ headache

3) Depletion of carbohydrate sources(tissue glycogen & blood glucose)

· CHO storage capacity in the body
- Blood glucose : 80~100㎎/100㎖ · blood(total 4~5g, 20㎉)
- Liver glycogen : 75~100g(300~400㎉)
- Muscle glycogen : 13~15g/㎏ · muscle(total 375~450g, 1800~2200㎉)

*** Depletion of glycogen(in muscle)**

- Ex. intensity : 65~90% of VO_2max
- Ex. duration : 2~3hrs
  cf) "hitting the wall"(약 32㎞ 지점에서)

※ Ergogenic Aids

· Glycogen supercompensation(Carbohydrate loading)
: Ron Hill, European Championship in Athens, 1969)
⇒ 일반적으로, exhaustion 상태를 초래하는 90min 이상 지속되는 운동시에 필요
(예, soccer, marathon, triathlon, ultramarathon, cross-country skiing 등)

Training and diet regimen for carbohydrate loading

Day	Training	Eating
1	90min, 70~75% of VO_2max	50% CHO 5gm/kg
2	40min, 〃	〃 〃
3	40min, 〃	〃 〃
4	20min, 〃	70% CHO 10gm/kg
5	20min, 〃	〃 〃
6	Rest 〃	〃 〃
7	Event	Event

· CHO suppl. in pre-exercise
- 운동 1hr 이전에는 약 1g/kg · body wt.(↑consuming CHO during exercise)
- 운동 3~4hr 이전에는 약 4g/kg · body wt.(↑glycogen stores)

참고) Pre-exercise CHO : low-fiber, low-fat, complex CHO(starches)
(⇒ 운동중 hypoglycemia를 초래하는 insulin 반응 때문)

· CHO suppl. during exercise
: 2hr 이내의 운동시
- 운동직전 : 5~7% CHO drink, 200~400㎖
(preferably as glucose polymers)
- 운동중 : 5~7% CHO drink, 100~150㎖, at 10~15min interval

· CHO suppl. after exercise
- exhaustion exercise 후 2hr 이내에 CHO feeding
- 4~6 hr 에는 매 2hr 마다 simple sugar
(0.7g glucose or sucrose/kg · body wt. or 50g CHO)
- 6hr 이후에는 complex CHO
- 20~24hr 경과시, total 500~700g CHO
(preferably low-fiber, low-fat foods : much like a pre-ex, meal)

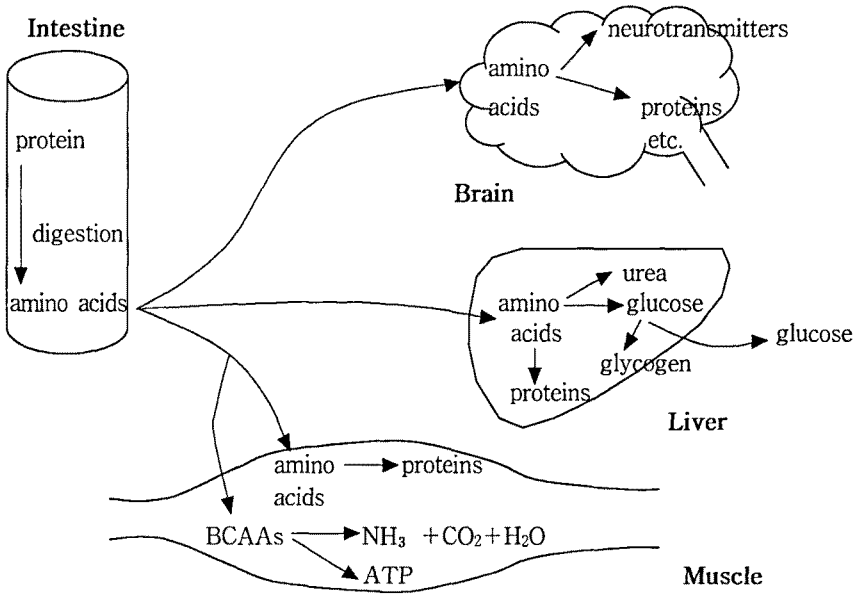
· Caffeine supple.
- Claim : · ↑alertness/↓sensation of fatigue(CNS stimulant)
· ↑force of muscle contraction
(↑Na^+-K^+ pump activity/Ca^{++} movement)
· ↑fat utilization(by ↑plasma epinephrine/↓phosphodiesterase activity)
cf) - 3~6㎎/kg · body wt., taken 1hr before exercise
- IOC doping threshold : ↑12㎍/㎖ in urinary levels
- Facts : · glycogen sparing effects는 80%VO_2max에서 최초 약 15분 정도로 제한적임
· high caffeine consumption(약 ↑9㎎/kg · body wt.)
: nausea, muscle tremors, palpitation, headache

* **Reduction of Blood Glucose(⇒Central fatigue)**
  - Ex, intensity : 60~65% of VO_2max
  - Ex. duration : 60~150min
    cf) · 70㎎/dℓ : performance deteriorates rapidly
    · ↓ 45㎎/dℓ : hypoglycemia
    (impair pace/orientation, nausea, irritability, dizziness, loss of consciousness)

※ Ergogenic Aids

· Fructose suppl.
  - Claim : to satisfy the need for large amounts of CHO without excessive elevating blood glucose
    [cf, ↑ blood glucose
    → ↑ insulin → ↓ lipolysis(for endurance exercise)]
    ⇒ sucrose : converted to liver glycogen without appearing as blood glucose
  - Facts : · large-scale metabolism of fructose by the liver
    ⇒ to deplete ATP levels in the liver
    to produce a serious energy deficit(→liver damage)
    · gastric distress

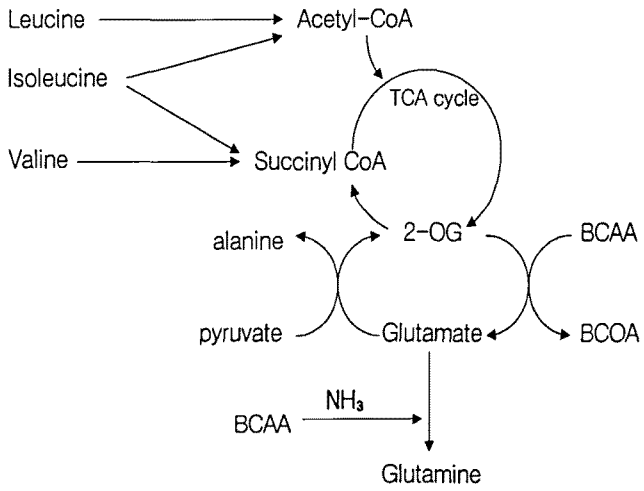
4) Changes in the concentration of key amino acids(in blood)
(⇒Central fatigue)
· key amino acids : - BCAA(branched-chain amino acids : leucine, isoleucine, valine)
- Tryptophan



Summary of amino acid metabolism

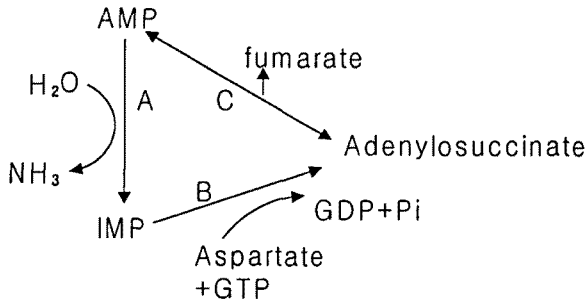
* BCAA
  - fuel-providing role in muscle
  - maint source of ammonia production(peripheral/central fatigue)

· BCAA metabolism(BCAA aminotransferase Rx.) in the ammonia production
- Ex. intensity : 65~85% of VO_2max
- Ex, duration : ↑ 1hr

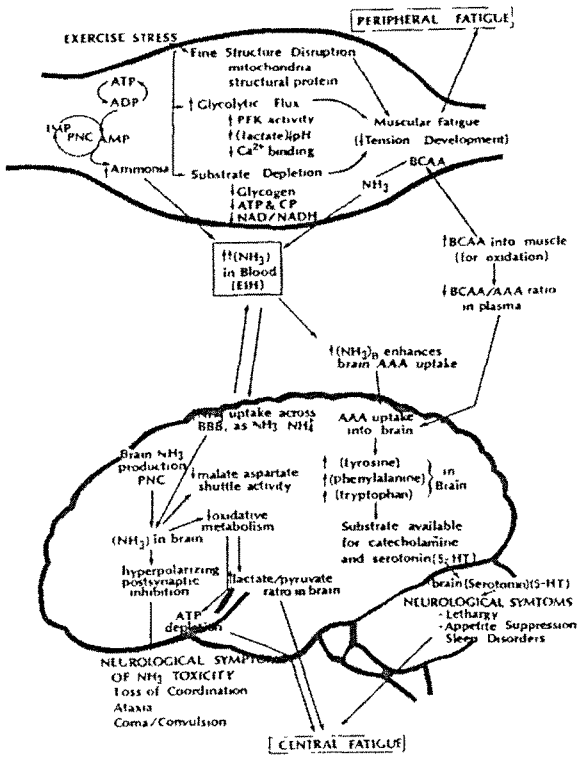


Summary of BCAA metabolism

cf) Producing of ammonia in skeletal muscle by net breakdown of ATP(PNC : purine nucleotide cycle)
· Ex. condition : ≒ 70% of VO_2max(ATP utilization>ATP resynthesis)
⇒ rely on recruitment ratio of fast-twitch fiber



The purine nucleotide cycle(PNC).
Enzymes involved in reactions of the cycle are :
A : adenylate deaminase
B : adenylosuccinate synthetase
C : adenylosuccinase

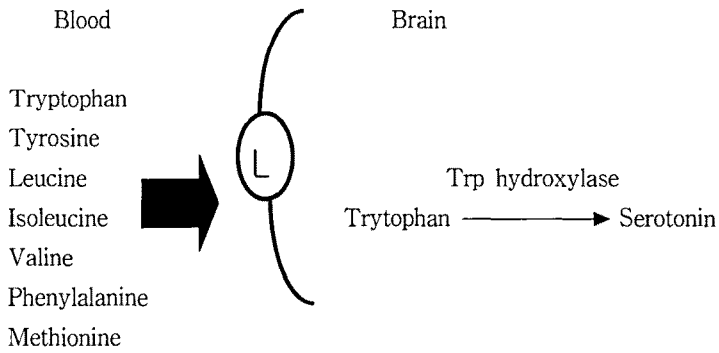


*** Pathways of ammonia toxification during exercised-induced hyperammonemia(EIH)**

* Tryptophan

(⇒ serotonin : 5-hydroxytryptamine, 5-HT)

: tiredness, sleep, decrease in aggression



Competition for uptake of the large-neutral amino acids by the L-transfort system(L) at the blood-brain barrier

cf) Changes during exercise

- ↑ BCAA uptake in muscle
- ↑ FFA(⇒ ↑ free-Trp) in plasma

· ↓ Trp uptake in liver
· ↑ Pasma ratio of free-Trp/BCAA
· ↑ Brain Trp
· ↑ Brain 5-HT(⇒ Central fatigue)

※ Ergogenic Aids

· CHO suppl.
- Claim : ↑ blood glucose → ↑ insulin → ↓ lipolysis → ↓ plasma FFA → ↓ plasma free-Trp → ↓ brain Trp → ↓ brain 5-HT
- Facts : ↑ blood glucose → ↑ insulin → ↑ plasma ration of free-Trp /BCAA(↓ plasma free-Trp/ ↓ ↓ ↓ LNAA)→ ↑ plasma free-Trp → ↑ brain Trp → ↑ brain 5-HT

· BCAA suppl.
- Claim : ↑ plasma BCAA → ↓ plasma ration of free-Trp/BCAA → ↓ brain Trp → ↓ brain 5-HT
- Facts : BCOAD(branched-chain 2-oxo acids dehydrogenase) complex activation → ↑ BCAA aminotransferase Rx.(excessive breakdown of BCAA)
⇒ · ↑ plasma ammonia conc.(fatigue)
· ↓ 2-oxoglutarate
(reducinig the flux in TCA cycle→impeding fuel oxidation
· ↓ glutamine
(immnue dysfunction ⇒ URI symptom)

5) Hypohydration
- ↓ plasma volume(↑ HR)
- impaired thermoregulation
⇒ reduction in aerobic exercise performance
(when fluid losses exceed 3~5% of body weight)
cf) 6~10% of body weight : heat stroke

Adverse Effects of Dehydration

% Body wt. loss	Symptoms
0.5%	Thirst
2.0	Stronger thirst, vague discomfort, loss of appetite
3.0	Increasing hemoconcentration, dry mouth, reduction in urine
4.0	Increased effort for exercise, flushed skin, impatience, apathy
5.0	Difficulty in concentrating
6.0	Impairment in exercise temperature regulation, increased HR
8.0	Dizziness, labored breathing in exercise, mental confusion

10.0	Spastic muscles, inability to balance with eyes closed, general incapacity, delirium and wakefulness, swollen tongue
11.0	Circulatory insufficiency, marked hemoconcentration and decreased blood volume, failing renal function

cf) Guidelines for prevention of thermal injury during endurance exercise in the heat(>30℃)

㉮ 운동 20~30분전에 cold water(5~15℃)(or dilute electrolyte drink) 500㎖ 섭취

㉯ 운동 중 매 15~20분(or 2~3㎞)마다 100~200㎖의 cold water(5~15℃) (or dilute electrolyte drink) 섭취

6) Hyponatremia

sweat loss(>30℃, >80% relative humidity)의 양이 과도한 조건에서

: symptoms of low blood sodium

→ lethargy, muscle cramping, mental confusion, seizures

* Sodium supple.

: One salt tablet(약 0.2g)/0.45㎏ · body wt. loss

· 체중의 2㎏ 이상 sweat loss인 경우

· 4시간 이상 지속되는 고강도 submaximal exercise를 수행하는 경우

결 론

이상에서 살펴본 것처럼, 운동수행 향상을 위해 섭취하는 ergogenic aids는 운동강도, 운동기간은 물론 환경적인 요인 등에 의해 초래되는 문제점들을 보완하고 개선시키는 측면에서 선수들에게 많은 호응을 얻고 있다. 그러나, 섭취하는 ergogenic aids는 이점뿐만이 아니라 부작용을 갖게 할 수도 있으며, 심지어 선수의 건강에도 악영향을 미칠 수 있다. 특히, 섭취하는 제제가 food(or dietary supplement)이더라 하더라도 의학적인 효과를 주는 것이라면, 그것은 단순히 ergogenic aids가 아닌 drug으로 고려되어야 할 것이다.

따라서, 연구자들은 모든 ergogenic aids를 보다 다각적으로 심도있게 연구하여 사용시 안전성과 효과성을 입증해야 할 것이다. 더불어, 판매자 및 광고주는 해당 ergogenic aids의 효과만을 과도하게 부각시키지 말고 가능성 있는 부작용(side effects)을 소개하여야하며 기능성을 구체화시키는 노력이 필요하다고 사료된다.