

影響運動後乳酸變化因素探討

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摘要

乳酸是能量代謝之最終產物。運動後血液及肌肉中乳酸濃度常被當做運動強度指數。近年來，由於乳酸測量技術之進步及檢測儀器之大量製造，使得許多教練及研究人員能夠經常在運動時進行乳酸檢測以做為預測運動表現及做為開立運動處方之基本依據，因此建立乳酸測量值之精確而敘述完整之分析就顯得十分重要。研究結果發現運動強度與訓練狀態、肌肉型態、營養物質、運動型態與恢復方式等與受測者本身有關、高地運動與環境有關、血樣採集部位則與採樣方式有關。

本篇文獻回顧之目的旨在探討影響運動時乳酸測量之因素。了解這些因素對乳酸變數之影響程度是培養以乳酸濃度分析訓練效果之準確性及專業性之基本要求。

Factors Influencing Lactate Concentrations Following Physical Exertion

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Abstract

The purpose of this article was to review factors that influence lactate measurement during exercise. To understand those factors is of importance in developing an accurate and professional lactate analysis.

Lactate is a metabolic end product. Post-exercise lactate levels have been considered as an index for measuring exercise intensity. Because of improvement in measuring technology, many coaches and researchers, in recent years, have had an opportunity to use a lactate analyzer to assay lactate levels generated during exercise. Lactate data has been applied to predict exercise performance and to establish exercise prescription. From the scientific studies, it has been found that test subjects (exercise intensity and training status, muscle fiber type, substrate utilization, type of exercise, and recovery), environment (altitude and ambient temperature), and blood sampling techniques must all be considered when performing lactate measurements.

壹、前言

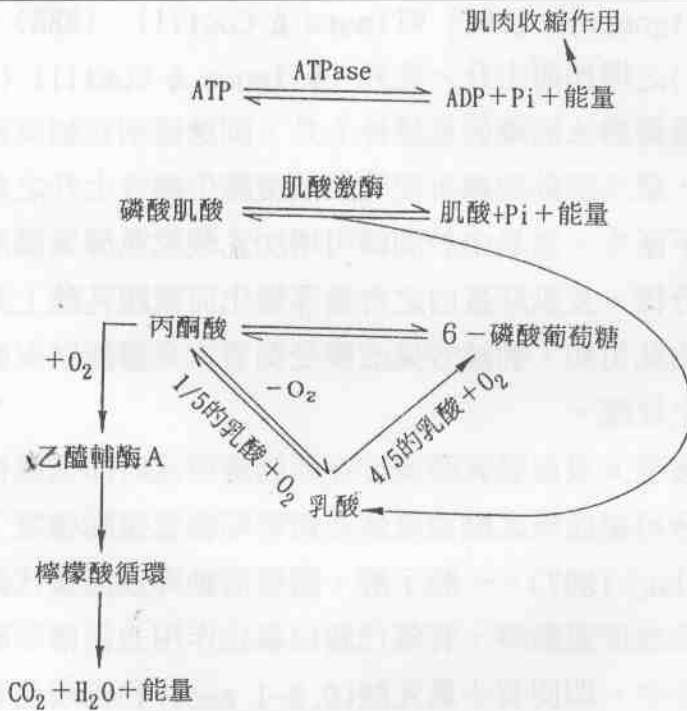
—— 乳酸是能量代謝之產物（圖一）。運動後血液及肌肉中乳酸濃度常被當做運動強度指數。許多運動研究顯示乳酸濃度常被當做運動強度指數。許多運動研究顯示乳酸濃度隨著漸增負荷之跑步(wELTMAN, 1995; Yoshida, 1984ab)、游泳(Lu, 1997; Madsen & Lohberg, 1987; Wilmore & Costill, 1988)、溜冰(Underwood, 1987)運動強度及耗氧量(Lu, 1991; Lu & Montgomery, 1991; Wilmore & Costill, 1988)、功率(Ivy et al., 1981)之增加而上升。此外, Wilmore & Costill (1988)發現乳酸濃度漸增負荷游泳訓練前呈線性上升, 訓練後則在較高游泳強度時才呈線性上升, 顯示運動訓練可使乳酸濃度產生線性上升之效應應在較高之運動強度下產生。這是由於訓練可增加乳酸脫氫酵素濃度、粒腺體密度、微血管分佈、及肌紅蛋白之含量等變化而減緩乳酸上升(Fox et al., 1993)。由此可知, 訓練效果改變受測者本身體能狀況影響乳酸濃度對運動強度之反應。

最近研究發現大鼠血漿乳酸濃度在低強度游泳時即呈線性上升, 表示實驗動物游泳可使血液乳酸濃度能在短時間較低運動強度下產生較快速上升之效應(Lu, 1997)。一般了解, 體能活動導致能量代謝增加, 當進行長時間、低強度運動時, 有氧代謝以氧化作用並供應三磷酸腺甘過程時並無乳酸產生。即使有少量乳酸(0.8-1 mmol/l)出現也有大部分經由氧化而成為水及二氧化碳、轉換為肌肉或肝臟肝醣、成為蛋白質構成物、轉換為葡萄糖、及胺基酸等(表一)方式從體循環中移除(Gasser & Brooks, 1984)。而當清除率與製造率相等時沒有乳酸堆積產生。然而, 當運動強度增加至需以無氧醣分解合成三磷酸腺甘時, 工作肌群開始大量製造乳酸。當乳酸之製造率高於清除率時產生乳酸堆積(Gasser

(& Brooks, 1984)。

表一、乳酸代謝路徑及百分比

乳酸代謝路徑	百分比
氧化而成為水及二氧化碳	55% - 70%
轉換為肌肉或肝臟肝醣	20%
成為蛋白質構成物	5% - 10%
轉換為葡萄糖	2%
轉換為胺基酸	10%



圖一、肌肉收縮的能量供應與補充之化學反應。

近年來由於乳酸測量技術改良及儀器被大量製造，因此被廣泛運用於競技訓練及相關研究。運動後乳酸變化被許多學者訂定不同名稱如乳酸閾值、最大穩定狀態、無氧閾值、有氧閾值、個人無氧閾值、乳酸轉折點及乳酸開始堆積點等，基本上這些名稱都是解釋所測乳酸變數之現

象。由於這些變數常被教練及研究人員利用於預測運動表現及做為開立運動處方之基本依據，因此建立乳酸測量值之精確而敘述完整之分析就顯得十分重要。

貳、影響乳酸對運動反應之因素

研究結果發現運動強度與訓練狀態、肌肉型態、營養物質、運動型態與恢復方式等與受測者本身有關、高地運動與環境有關、血樣採集部位則與採樣方式有關。這些因素都會影響乳酸測量值，而增加正確的將測驗結果解釋及分析上之困難度。了解這些因素對乳酸變數之影響程度是培養準確而專業性分析之基本要求。

1. 運動強度與訓練狀態

研究顯示運動強度在75-120% $V_{O_2 \max}$ 時，體內乳酸開始大量上升(Bonen et al., 1979; Bonen & Belcastro, 1976; Bonen & Belcastro, 1977; McLellan & Skinner, 1982; Siebers & McMurray, 1981)而在低於40% $V_{O_2 \max}$ 時，乳酸濃度上升並不顯著(Gollnick et al., 1986; Stamford et al., 1981)。安靜時體內會產生1-2 mmol之乳酸(Fujitsuka et al., 1980; Ivy et al., 1987; Karlsson, 1970; Karlsson, 1971; Poortmans et al., 1978)，但很快就被氧化成水及二氧化碳(Mayes, 1985)，當因肌肉收縮而產生之乳酸量無法被即時清除量時，乳酸就開始堆積在肌肉及血液中(Brooks & Divine-Spurgeon, 1982; Gollnick & Hermansen, 1973; Jacobs, 1986)。

一般了解，耐力訓練增加肌肉細胞中粒腺體密度及有氧酵素之濃度與活性。這些訓練效果減少身體利用碳水化合物做為優勢能量供應系統，因而降低運動時肌肉乳酸之堆積(Saltin, 1976)。Coggan et al., (1992)將受測者分為高低乳酸閾值兩組。兩組攝氧量峰值無顯著差異，利用

攝取碳—¹³同位素標幟之葡萄糖進行追蹤。結果發現固定運動強度及時間條件下高乳酸閾值組使用葡萄糖比低乳酸閾值組使用率低。

2. 肌肉型態

運動後乳酸變化受到許多因素影響(Weltman, 1995)。根據許多研究顯示，乳酸濃度與肌肉有氧能力及肌肉型態有關(Ivy et al., 1980; Komi et al., 1981; Sjodin & Jacob, 1982; Tesch et al., 1981; Weltman, 1995)。Ivy et al. (1980)以進行腳踏車運動探討乳酸閾值與股外側肌群(Vastus Lateralis)有氧能力及慢縮肌纖維百分比之關係。結果發現，運動後乳酸濃度與肌群有氧能力($r=0.95$)及慢縮肌纖維百分比($r=0.74$)顯著相關。以不同運動方式探討乳酸與肌肉型態之關係，Komi et al. (1981)發現跑步機運動引發乳酸堆積與慢縮肌纖維百分比($r=0.78$)顯著相關。Tesch et al. (1981)發現92%乳酸開始堆積點(Onset of Blood Lactate Accumulation; OBLA)與慢縮肌纖維百分比相關。以上研究報告乳酸與肌群有氧能力，顯示肌肉細胞中粒腺體密度可影響運動後乳酸變化。此外，乳酸堆積與慢縮肌纖維百分比之相關則顯示遺傳因子影響以訓練改變乳酸閾值之能力(Ivy et al., 1980)。

3. 營養物質

運動後乳酸也受營養物質濃度影響(Gollnick et al., 1981; Ivy et al., 1981; Yoshida, 1984)。Gollnick et al. (1981)利用食物控制及運動使一腳肌群肝醣下降，而後進行雙腳之腳踏車運動。結果發現雖然運動時雙腳之出功率相同但肝醣下降腳之乳酸濃度低於正常腳。Ivy et al. (1981)先將受測者分成控制組、運動開始前30分鐘攝取葡萄糖溶液、及增加游離脂肪酸，以漸增負荷腳踏車運動引發乳酸上升，結果顯示控制組與葡萄糖組乳酸相同上升趨勢，而增加游離脂肪酸卻顯著減少運動後乳酸上升程度。Gollnick et al. (1981)及Yoshida (1984)以

3-4天混合食物、低碳水化合物、及高碳水化合物後分別進行次最大強度運動(Submaximal Exercise)，結果發現攝取高碳水化合物食物組增加運動後乳酸濃度上升程度。

根據生理對體能訓練反應之研究顯示訓練狀態影響運動後乳酸濃度變化。MacRae et al. (1992)報告8名非運動員進行9週耐力訓練後乳酸濃度在每個運動耗氧量(運動強度)下皆顯著下降。許多學者認為訓練後乳酸濃度下降現象歸因於訓練對運動後乳酸製造率減少或/和乳酸清除率增加(Donovan & Brooks, 1983; Donovan & Pagliassotti, 1990; MacRae et al., 1992; Stanley et al., 1985)之效應。此外，訓練減少運動後碳水化合物之利用(Saltin et al., 1976)及因訓練增加肌肉內粒腺密度與有氧酵素活性(Holloszy & Coyle, 1984)而減少乳酸堆積(Saltin et al., 1976)程度。

4.運動型態與恢復方式

許多研究指出運動型態可影響乳酸。Ohkuwa & Miyamura (1984)發現衰竭運動時短跑選手乳酸峰值(19 mmol/l)高於耐力選手(15 mmol/l)。而短跑選手乳酸峰值出現於衰竭運動開始後5-10分鐘而耐力選手則在運動開始後5-7.5分鐘出現乳酸峰值。Weltman et al. (1990)以比較連續及非連續運動測試對乳酸之影響。連續運動測試是每3-4分鐘增加跑步速度(10 m/min)，而非連續運動測試則是分別以3次跑完共9次之10分鐘跑步。結果發現以耗氧量及跑速為強度指標時，連續運動測試時乳酸濃度在各強度皆低於非連續運動測試結果。

一般了解，運動後恢復方式可影響乳酸濃度。高強度運動後如進行次最大強度運動可以加速血流、促進肌群有氧代謝、增加乳酸由肌肉中移出、及將乳酸運至其他組織以進行有氧代謝方式增加清除率(Gollnick et al., 1986)而降低乳酸濃度。Montgomery (1988)發現運動後乳酸濃

度在高強度間歇溜冰中進行靜坐、自選強度溜冰運動、及以40%最大耗氧量強度腳踏車運動分別為10.6、10.8、8.5 mmol/l。結果顯示，高強度間歇溜冰中進行40%最大耗氧量強度腳踏車運動有較強降低乳酸濃度之效應。Bonen & Belcastro, (1976)在高強度運動後以57%—70%最大耗氧量強度進行平面跑步運動，結果發現乳酸濃度每分下降7.1 mg/dL (0.8 mmol/L)。McLellan & Skinner, (1982)報告以59%最大耗氧量強度進行上坡跑步運動進行恢復使乳酸濃度每分下降9.3 mg/dL (1.1 mmol/L)。以上證據顯示，動態恢復時運動型態及強度影響乳酸濃度。

5.高地運動及大氣溫度

Brooks et al. (1991a)將7名受測者暴露於4300公尺高地，發現進行次最大強度運動時乳酸濃度顯著高於平地運動，而隨著3週高地適應，運動後乳酸濃度與平地差異變小。高地適應被認為可提高肝醣在安靜及運動使用率，並減少以乳酸製造率(Brooks et al., 1991b)。此外，在溫度較高之環境運動，造成乳酸快速上升(MacDougall et al., 1974)，而在溫度較低環境下，乳酸閾值則在較高之運動強度時出現(Flore et al, 1992; Therminarias et al., 1989)。

6.血樣採集部位

血樣採集方法也影響乳酸測量值。Yoshida (1984a)比較每1分鐘及4分鐘漸增負荷之腳踏車運動動脈及靜脈血液中乳酸濃度。結果發現1分鐘腳踏車運動後靜脈血液中乳酸濃度高於動脈，而在4分鐘運動則無差異。Yoshida (1984)認為每分鐘漸增負荷之腳踏車運動並未達到穩定狀態而導致靜脈乳酸濃度增加。

參、總 結

以上文獻顯示，高強度運動時乳酸變化是一個複雜之生理現象。因此建立完整而固定之運動測驗模式及標準化血樣採集處理方法在進行運動時乳酸代謝之相關研究是十分重要。

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