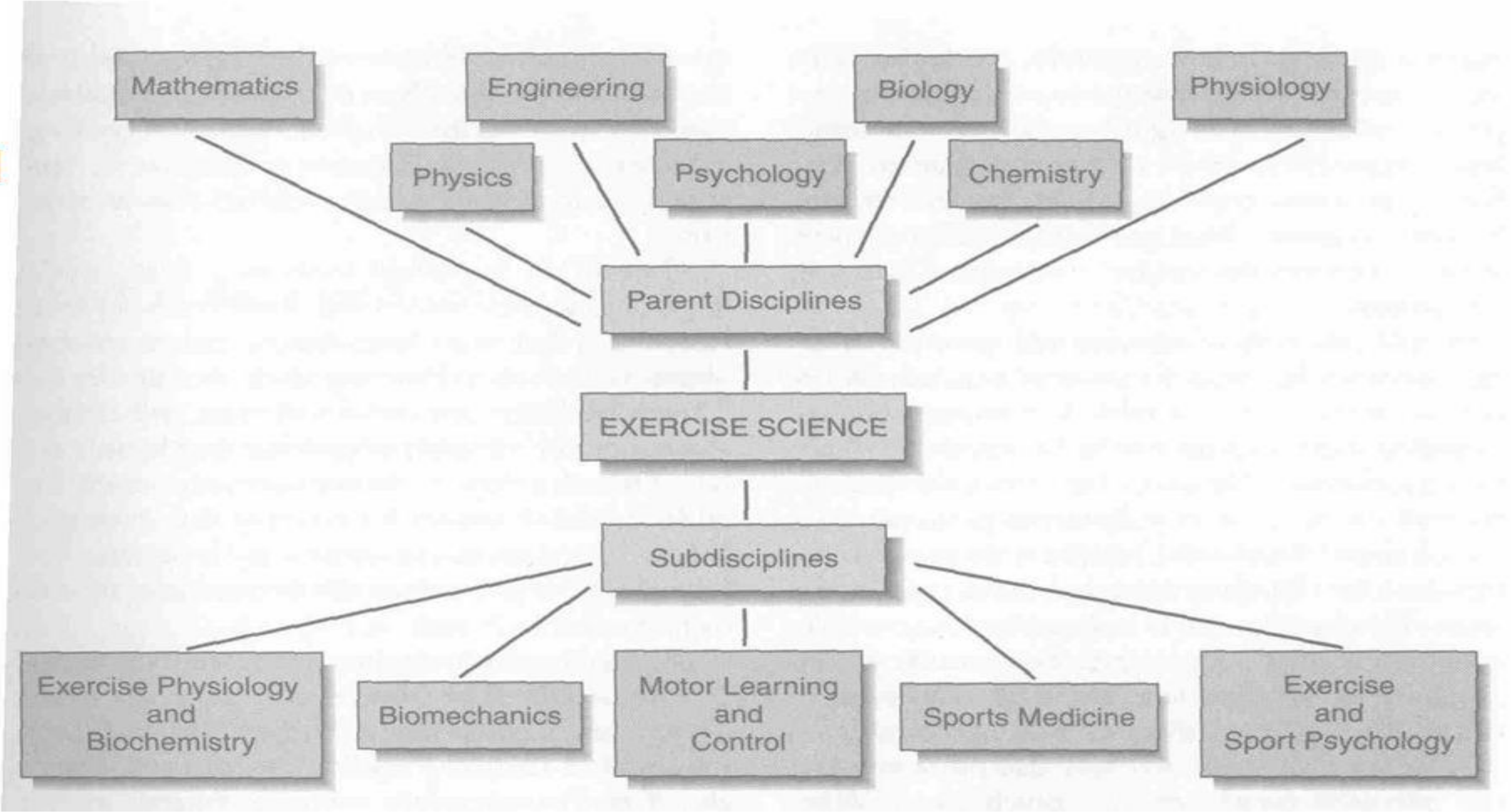
運動科學 Sports Science



運動營養學

Sports Nutrition

Nutrition for sport and exercise

- 運動營養是將營養學的基礎應用於運動領域上，目的在提升運動表現、體能或健康。
- 請問您一周運動是否達到4-6天、一天是否超過1小時？

Regulation of muscle growth and regeneration by the immune system

The Role of Satellite Cell and Immune Response

謝朝傑營養師

熱愛運動科學的營養師：謝朝傑
jay_dietitian

We all know that…..

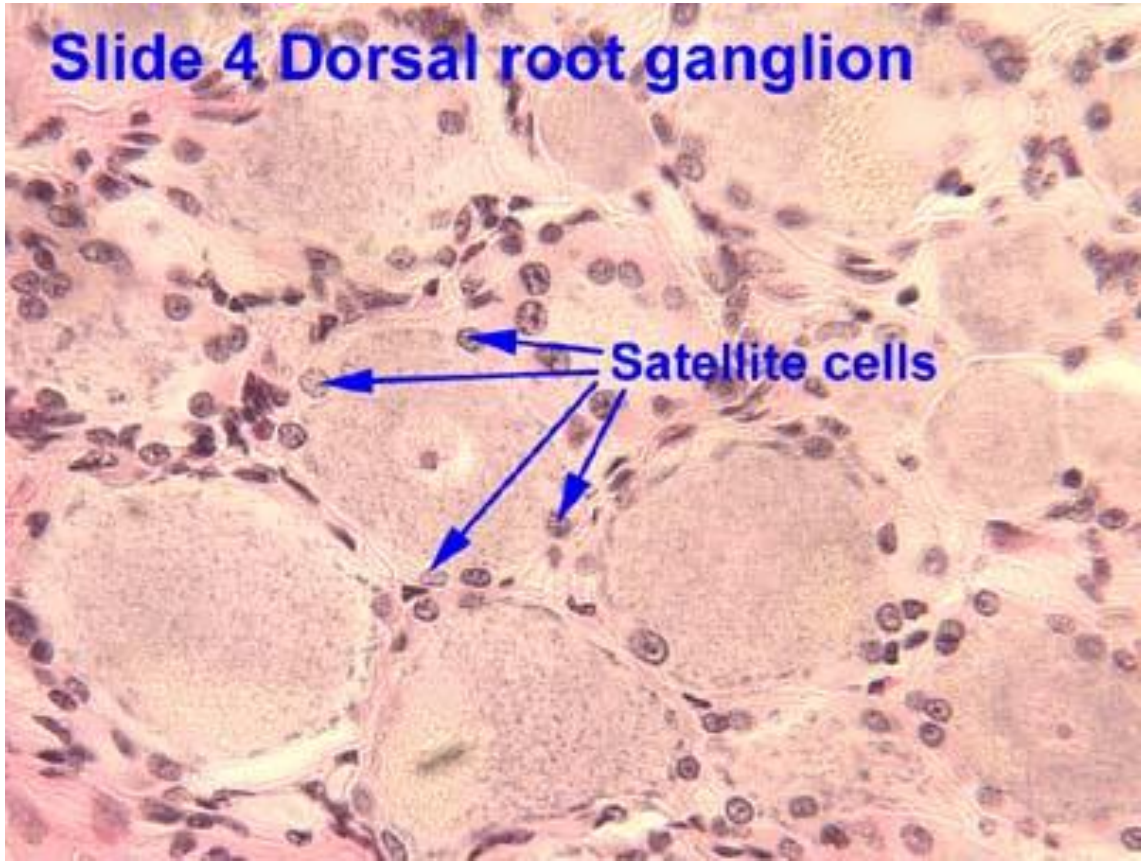
1. Resistance exercise make you strong
2. Exercise-induced damage leads to muscle growth
3. Damage → Inflammation → Muscle regeneration

BUT

- How is the relationship between Regeneration and inflammation?

History of Satellite cells

In 1961, Rockefeller University biophysicist **Alexander Mauro**, using electron microscopy, first described **muscle stem cells**, calling them "**satellite cells**"



Satellite cells are the **only** cells able to repair muscle

Myonuclear accretion as the result of Satellite Cells Fusion

Once activated, satellite cells proliferate and differentiate in order to contribute to the repair of existing muscle fibres through the formation of new myonuclei, a process known as **myogenesis** [Blaauw B,2014].

It has been suggested that a single myonucleus only has control over a limited volume of cytoplasm, known as the **myonuclear domain** [Cheek DB,1985].

Accordingly, additional myonuclei are hypothesised to permit muscle fibre hypertrophy beyond a definite extent (* 2250 μm2), a postulate referred to as the '**ceiling theory**' [Petrella JK,2006].

The Ceiling Theory

- Similarly, it has been speculated that only when the relative magnitude of fibre hypertrophy exceeds a **certain threshold** (≥ ∼25% of cross-sectional area) are additional myonuclei required to sustain growth [Kadi F,2004].
- However, myonuclear accretion has been observed during periods of hypertrophy (∼ 18% of cross-sectional area) where this threshold is not met.

Myonuclear Content	Myonuclear Domain
Fibre Size	Fibre Size
↓	↓
Linearly Related	Logarithmic Relationship

Myogenesis and Regeneration

Myogenic Precursor Cells = Satellite Cells

When there is injured muscle

→Activate satellite cells → Proliferation

→Many daughter cells will begin to differentiation while others will return to the quiescent state (Self-renewal)

Quiescent satellite cells --> PAX7+MYOD–
Activated satellite cells --> PAX7+MYOD+

Early phase：Activation, Proliferation

Later phase：Differentiation, Growth

Tidball, J. G. (2017). Regulation of muscle growth and regeneration by the immune system. Nature Reviews Immunology, 17(3), 165.

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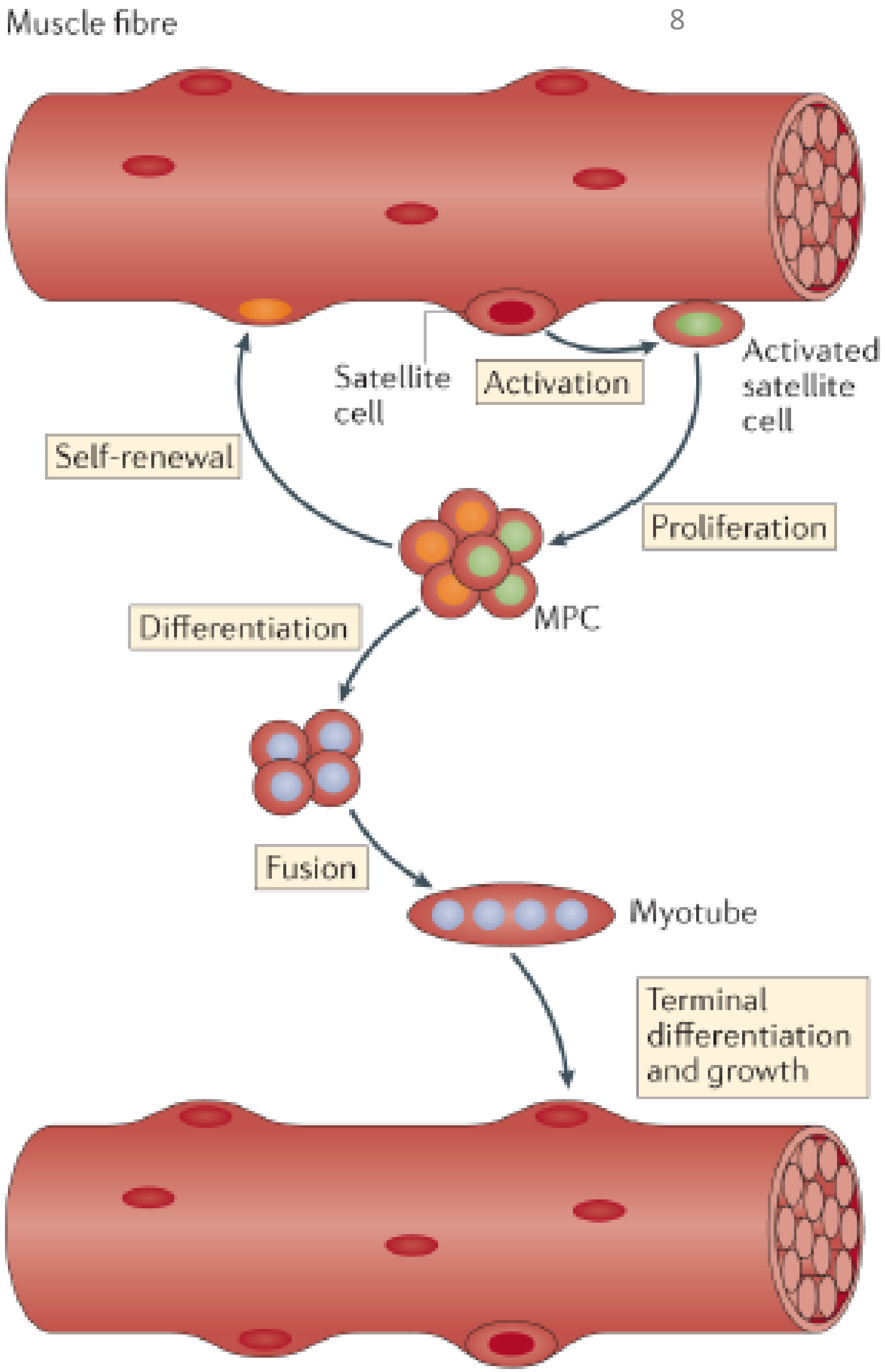
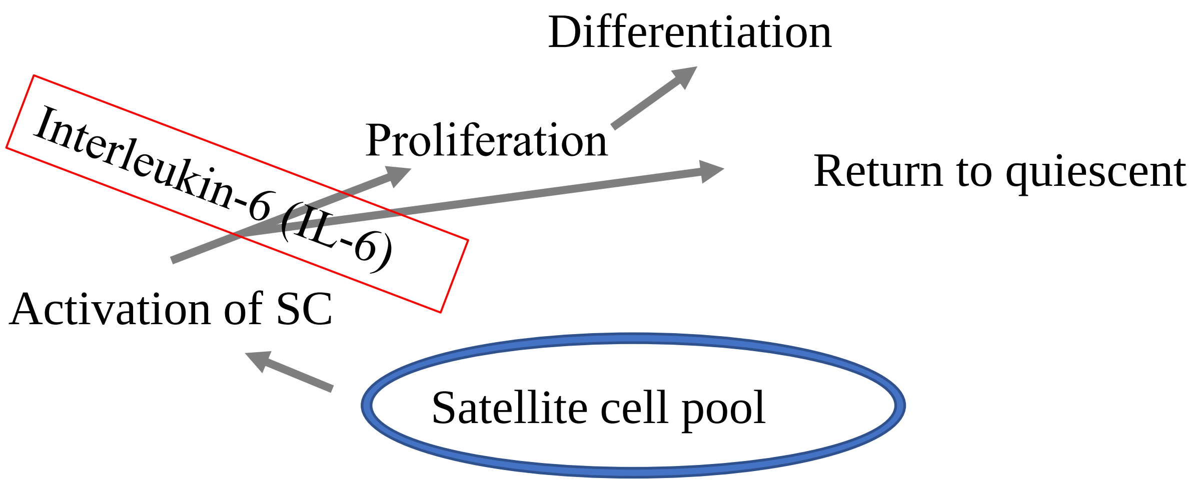


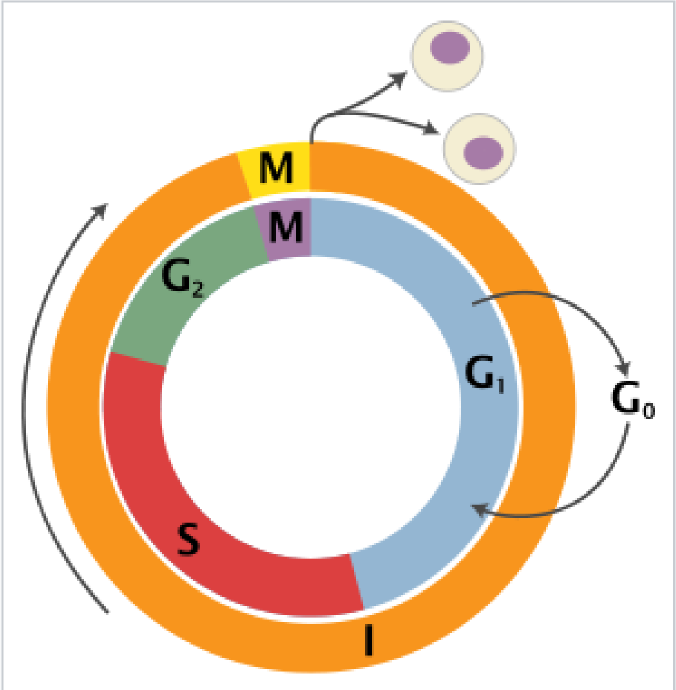
How to activate the muscle stem cells?

- Sources of SC activation

Ex: Mechanical stress, oxidative stress, inflammation

- The injured muscle itself was the source of ‘wound hormones’ that were released to activate satellite cells



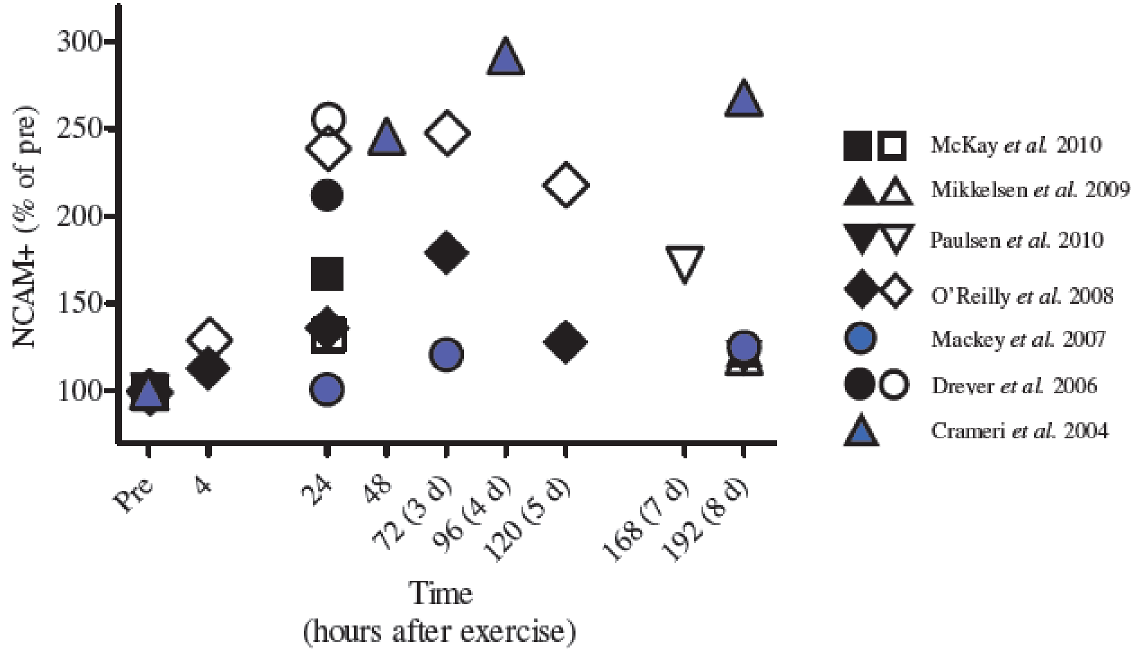


Schematic of the cell cycle. Outer ring: I = Interphase, M = Mitosis; inner ring: M = Mitosis, G_1 = Gap 1, G_2 = Gap 2, S = Synthesis; not in ring: G_0 = Gap 0/Resting[2]

Cell cycle Wikipedia

Satellite cell response to a single bout of maximal exercise.

Reference	Exercise mode (thigh muscle if not indicated)	Subjects' training status	Sampling time points	Measure of SC given:	Context and comments
Crameri *et al.* (72)	Eccentric exercise: 50 one-leg 'drop down' jumps 8x10 reps at 30°/s 8x10 reps at 180°/s	Sedentary	2 d 4 d 8 d	NCAM % MN	First study to show increased SC number with single bout of exercise
Dreyer *et al.* (84)	Max eccentric: 6x16 reps at 60°/s	No resistance training	1 d	NCAM % MN /fibre	Larger SC response in younger than in older subjects
Crameri *et al.* (71)	Max eccentric: 10x10 reps at 30°/s 11x10 reps at 180°/s	No regular training	4 d 8 d	NCAM, Pax7 % MN	Larger response with electrical stimulation. No baseline data given
O'Reilly *et al.* (225)	Max eccentric: 30x10 reps 180°/s	No resistance training	4 h 1 d 3 d 5 d	NCAM % MN, /fibre	Association with HGF response
McKay *et al.* (196)	Max eccentric: 3.14 rad/s 30 x 10 reps	No resistance training	4 h 1 d 3 d 5 d	Pax7 % MN	Association with IL-6 signalling
Mikkelsen *et al.* (202)	Max eccentric: 10x10 reps at 30°/s 10x10 reps at 120°/s	Well trained	5 h 28 h 8 d	NCAM, Pax7 % MN, /fibre	SC response reduced by NSAID infusion
McKay *et al.* (197)	Max eccentric: 3.14 rad/s 30 x 10 reps	No resistance training	1 d	NCAM, Pax7 % MN, /fibre	Compared with FACS, similar results
Paulsen *et al.* (230)	Max eccentric (elbow flexors): 14x5 reps at 30°/s	Physically active	1 h – 7 d (combined)	NCAM % MN, /fibre	Biopsies from m. biceps brachii



Paulsen, G., Ramer Mikkelsen, U., Raastad, T., & Peake, J. M. (2012). Leucocytes, cytokines and satellite cells: what role do they play in muscle damage and regeneration following eccentric exercise?. Exercise immunology review, 18.

Resident muscle stem cells are not required for testosterone-induced skeletal muscle hypertrophy

Davis A. Englund,[1,2]* Bailey D. Peck,[1,2]* Kevin A. Murach,[1,2] Ally C. Neal,[2] Hannah A. Caldwell,[2] John J. McCarthy,[2,3] Charlotte A. Peterson,[1,2] and Esther E. Dupont-Versteegden[1,2]

[1]*Department of Rehabilitation Sciences, College of Health Sciences, University of Kentucky, Lexington, Kentucky;* [2]*Center for Muscle Biology, University of Kentucky, Lexington, Kentucky; and* [3]*Department of Physiology, College of Medicine, University of Kentucky, Lexington, Kentucky*

Submitted 24 June 2019; accepted in final form 16 July 2019

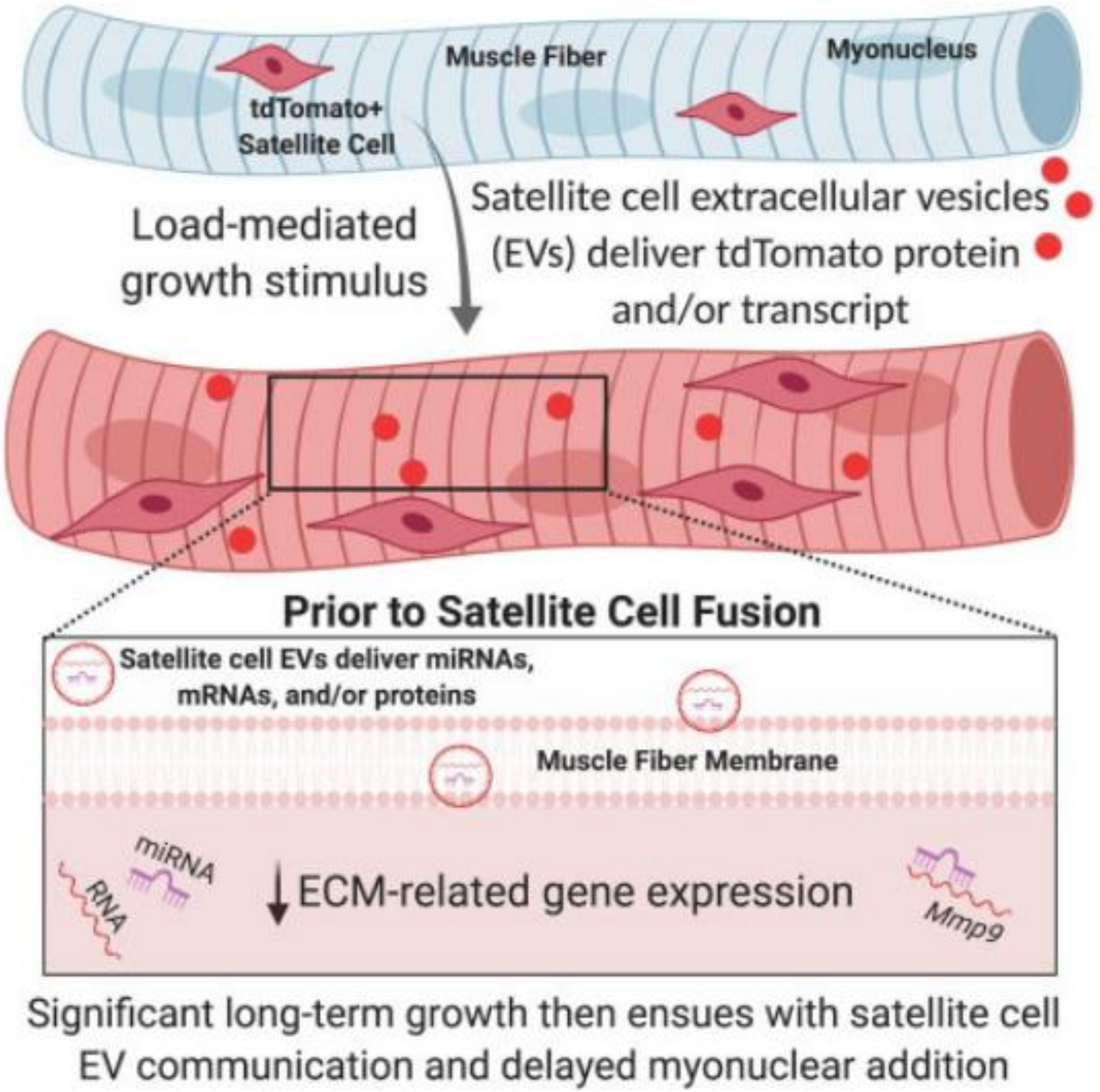
The findings of the present study demonstrate that the hypertrophic response to testosterone is unaffected by absence of satellite cells arguing against such a mechanism.

Results from other investigations show that satellite cell depletion effectively attenuates muscle fibre hypertrophy over both short-term (2 weeks) and long-term (8 weeks) overload.

Murach, K. A., Vechetti Jr, I. J., Van Pelt, D. W., Crow, S. E., Dungan, C. M., Figueiredo, V. C., ... & McCarthy, J. J. (2020). Fusion-independent satellite cell communication to muscle fibers during load-induced hypertrophy. Function, 1(1), zqaa009.

Extracellular vesicles EVs

- Cytoplasmic tdTomato (tdT) fluorescent protein (miRNA訊號)
- Occur in the early phase of mechanical load
- Satellite cells communicate with muscle fiber through Evs



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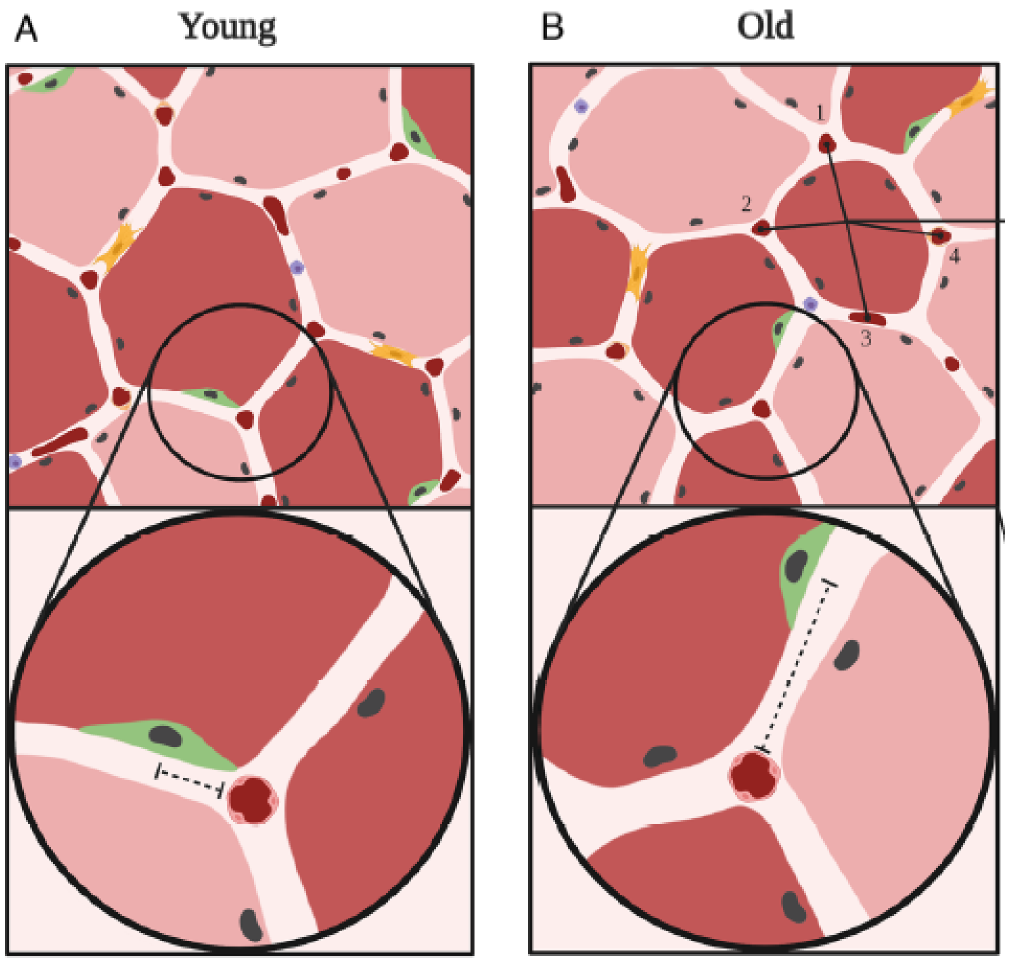
Murach, K. A., Vechetti Jr, I. J., Van Pelt, D. W., Crow, S. E., Dungan, C. M., Figueiredo, V. C., ... & McCarthy, J. J. (2020). Fusion-independent satellite cell communication to muscle fibers during load-induced hypertrophy. *Function*, *1*(1), zqaa009.

Muscle Satellite Cells

- 肌肉衛星細胞假說
- 初期：SC攜帶的mRNA訊號、本身含有的肌核
- 長期的肥大適應
- 活化→增生→分化→成長
- Self-renewal 機制

Aged muscle reduces cell-to-cell interaction because of the increased distance from each other

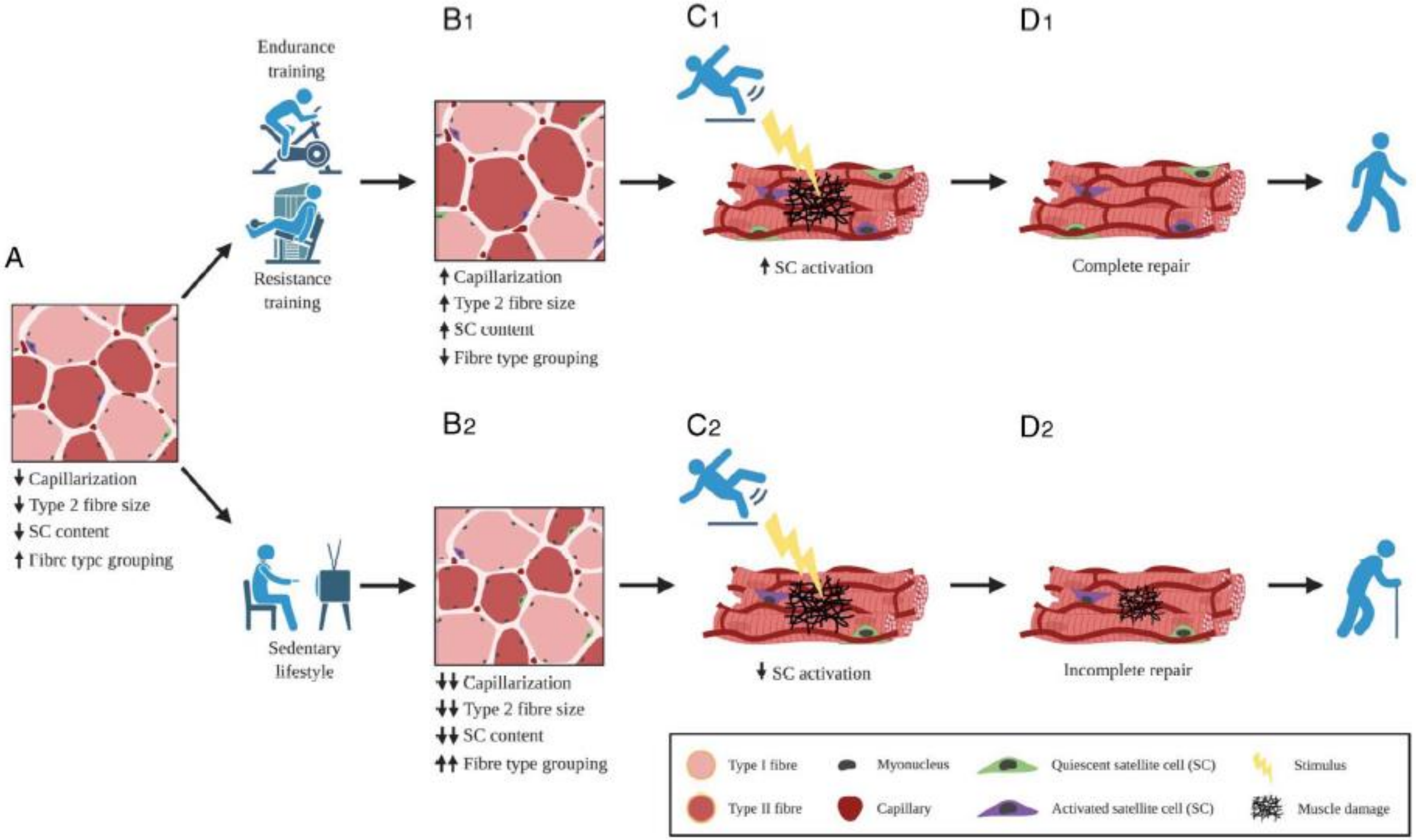


The cross section of an aged muscle fiber (B) is reduced in size and has lower capillarization and fewer SC, predominately in type II fibers. The expanded schematic indicates that muscle SC are located at a further distance from the nearest EC and capillary. We hypothesize that the increased distance reduces cell-to-cell interaction between these cell populations and represents an important mechanism underlying the reduced number of activated SC after a stimulus in older as compared with younger individuals.

Endothelial cells, Pericytes, SC

Nederveen, J. P., Betz, M. W., Snijders, T., & Parise, G. (2021). The importance of muscle capillarization for optimizing satellite cell plasticity. Exercise and Sport Sciences Reviews, 49(4), 284-290.

Sedentary lifestyle is the new smoking

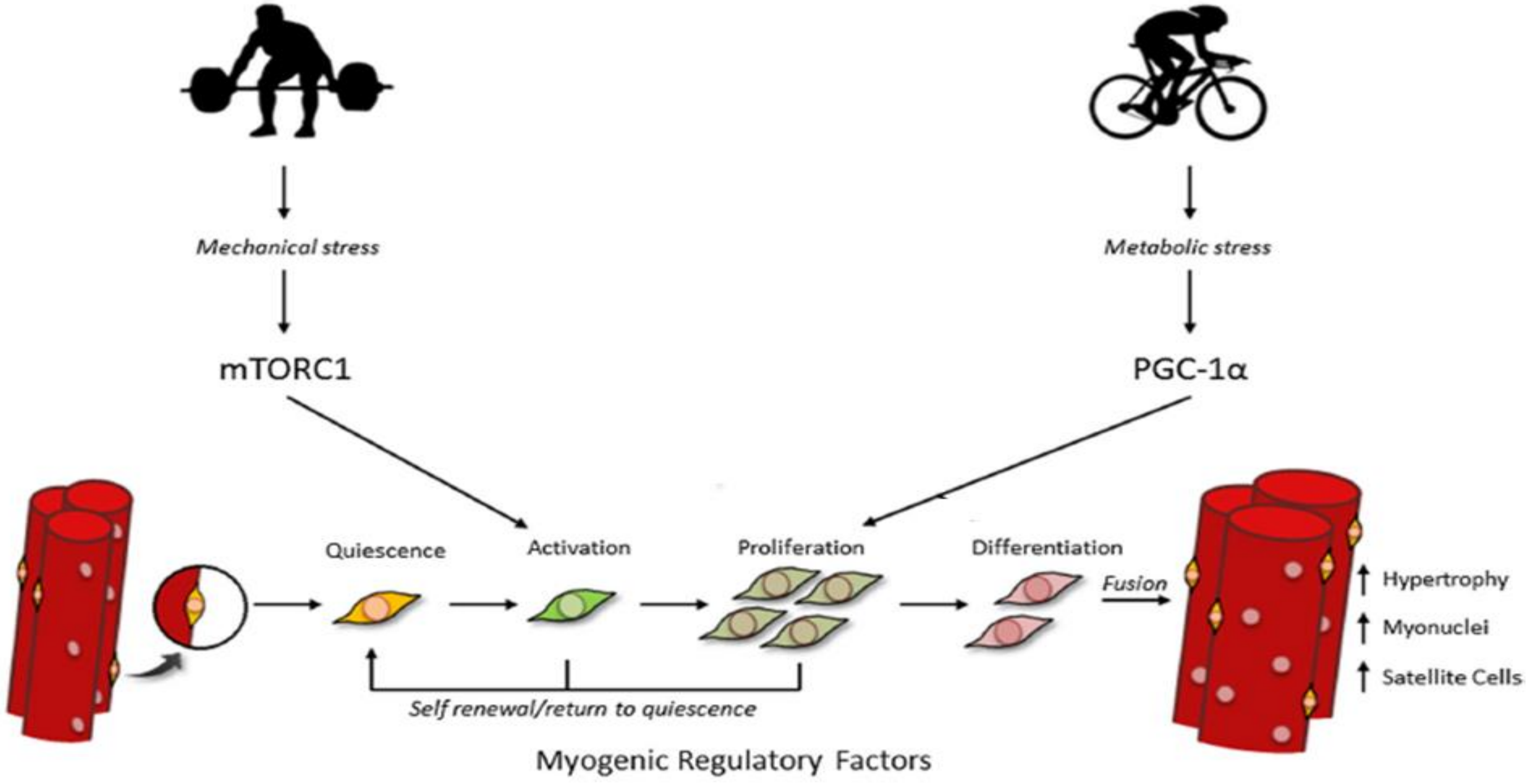


Optimizing SC number has, therefore, been hypothesized to be an important strategy in resisting the onset and development of age-related sarcopenia, which is often exacerbated during times of inactivity.

不同訓練使得肌肉肌核增加的可能機制

阻力訓練可以刺激機械性壓力→mTORC增加→使得肌肉衛星細胞的活化→肌核增加、肌肉肥大

耐力訓練可以刺激代謝性壓力→PGC-1a增加→使得肌肉衛星細胞的增生→肌核增加、肌肉肥大



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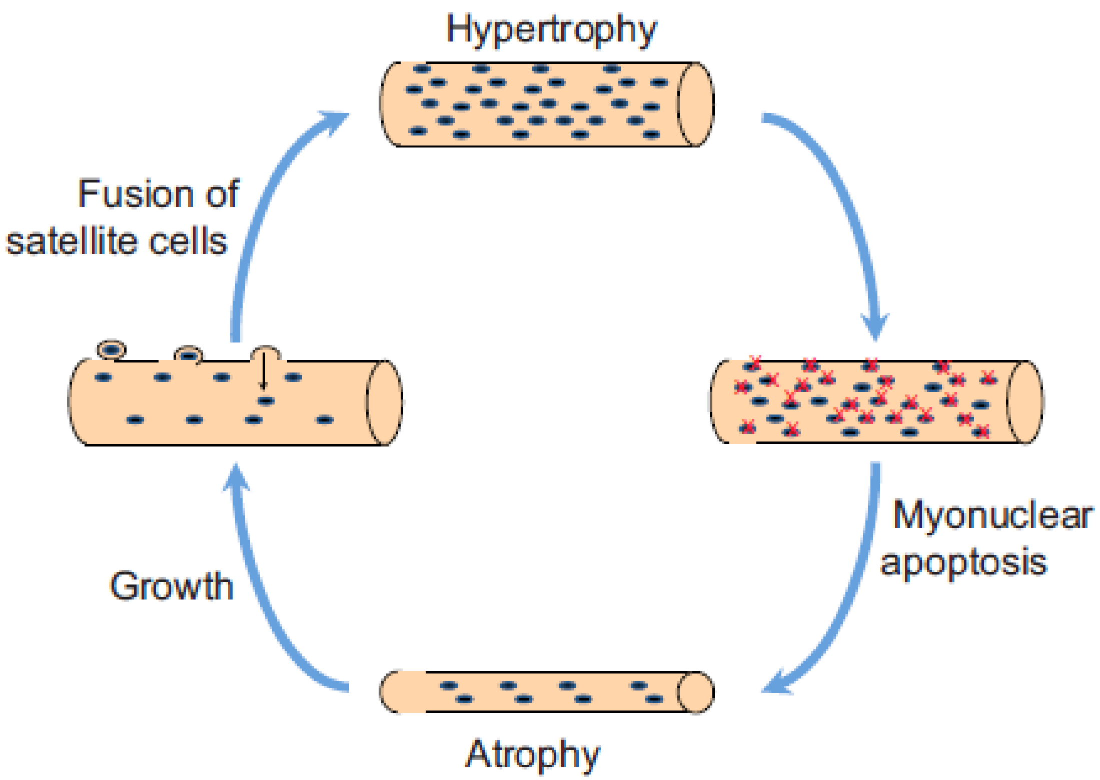
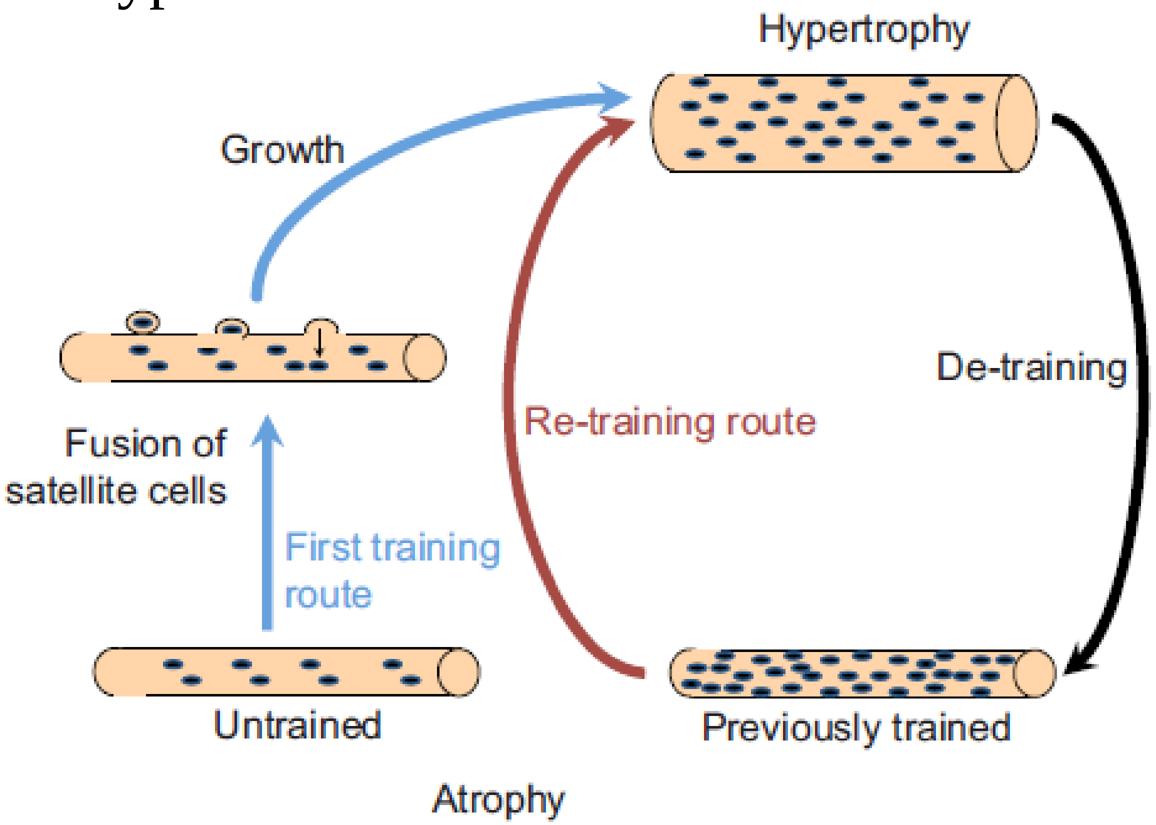
Shamim, B., Hawley, J. A., & Camera, D. M. (2018). Protein availability and satellite cell dynamics in skeletal muscle. Sports Medicine, 48(6), 1329-1343.

Muscle Memory

Textbook



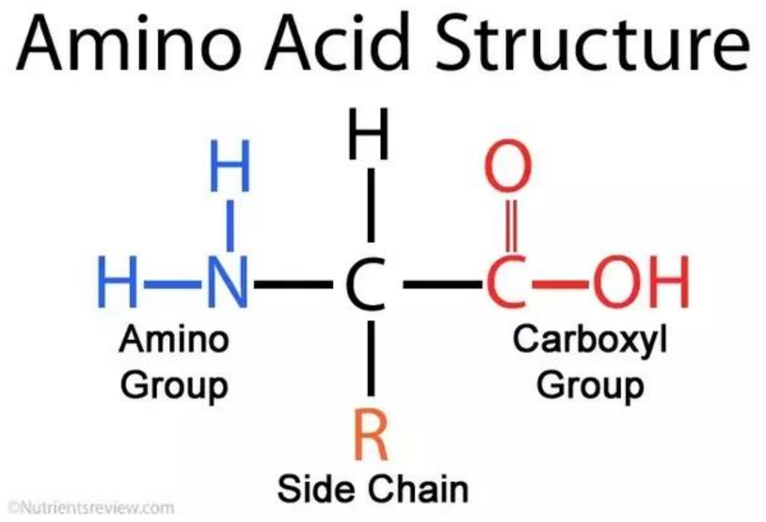
New hypothesis



Gundersen, K. (2016). Muscle memory and a new cellular model for muscle atrophy and hypertrophy. Journal of Experimental Biology, 219(2), 235-242.

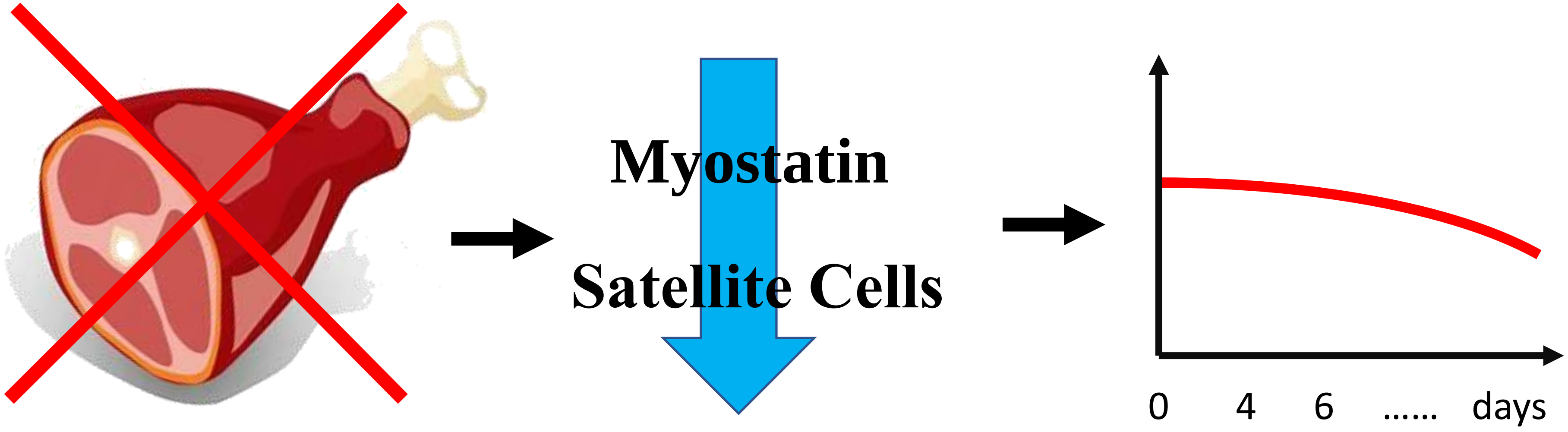
The Impact of Protein Ingestion on Satellite Cell Responses to Exercise

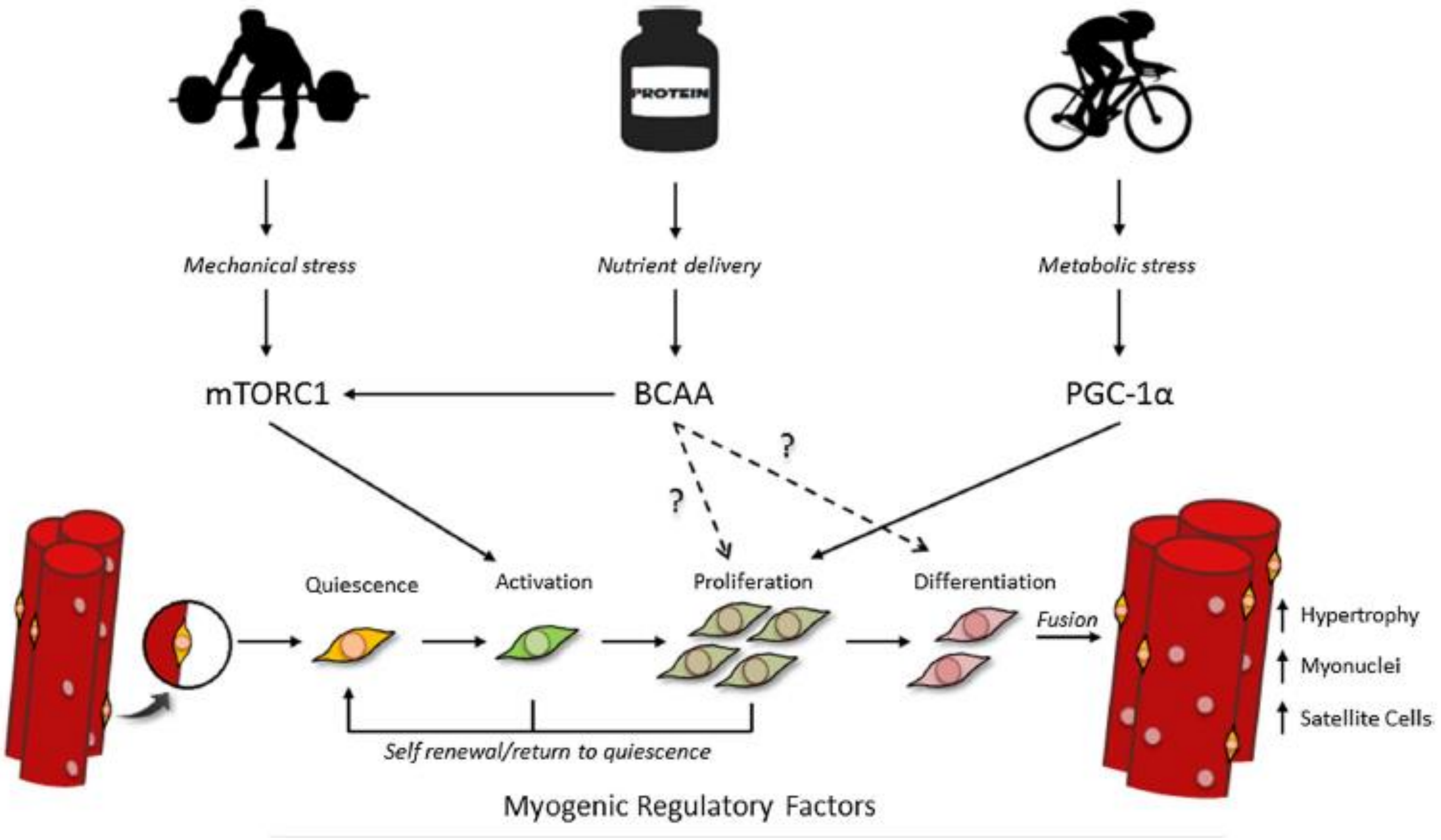
- Dietary protein, particularly branched chain amino acids, is a critical substrate for providing **amino acids** to facilitate skeletal muscle repair and regeneration during recovery from exercise.



Protein Restriction

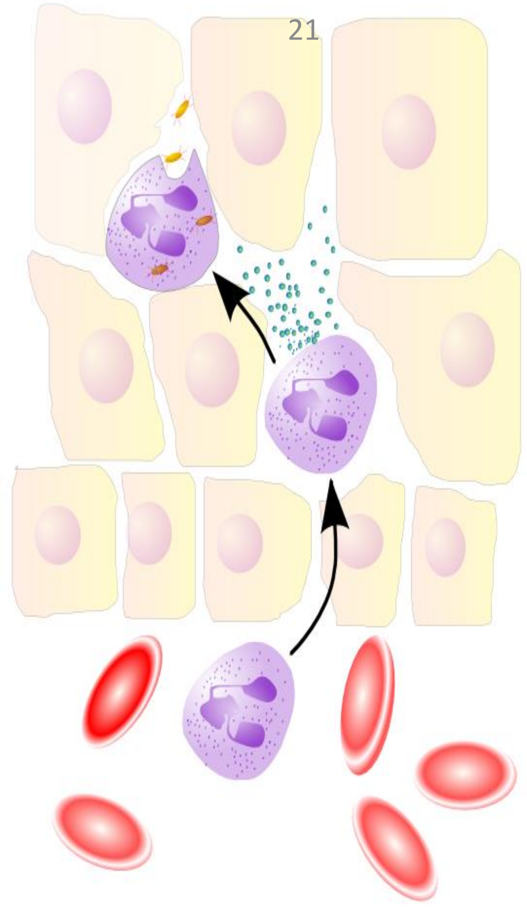
1. In the absence of dietary protein
2. The co-localization of **myostatin** with **satellite cells** remains **repressed** for a prolonged period
3. As a compensatory mechanism




Mechanical stress
Nutrient delivery
Metabolic stress
mTORC1
BCAA
PGC-1α
?
?
Quiescence
Activation
Proliferation
Differentiation
Fusion
Hypertrophy
Myonuclei
Satellite Cells
Self renewal/return to quiescence
Myogenic Regulatory Factors

Myeloid cell regulation and muscle regeneration

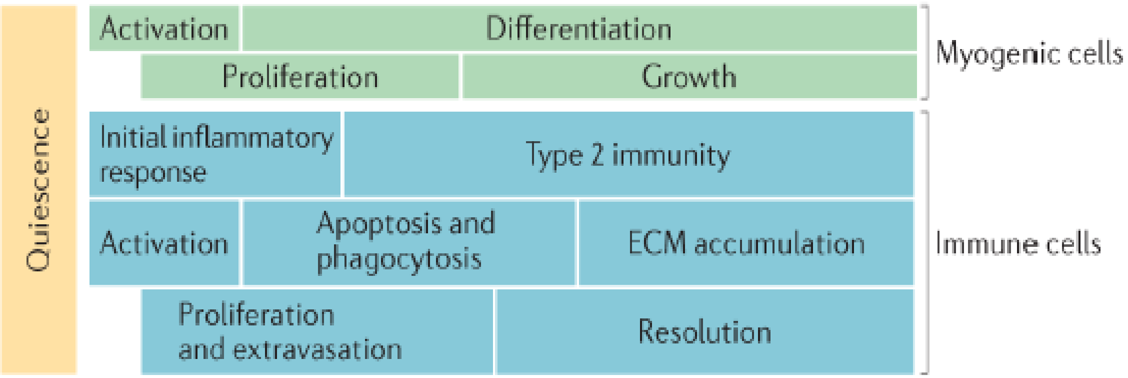
- Occur in first phase (Satellite Cell activation and proliferation)



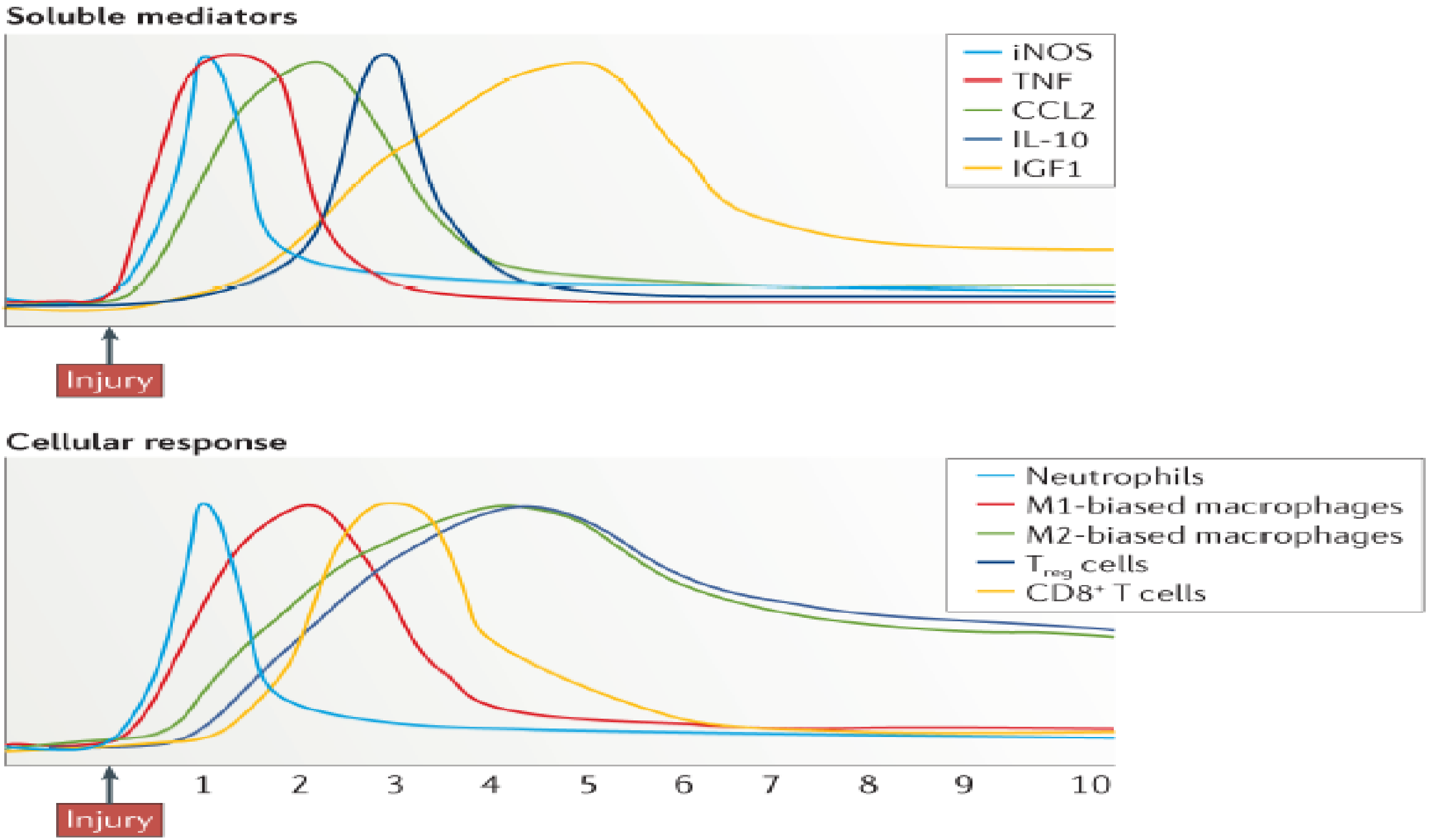
Wikipedia

1. Within hours, neutrophils invade damaged muscle and reach maximum numbers at approximately 12 to 24 hours post injury, after which they rapidly return to near-normal numbers→ Resident macrophages promote this marked neutrophil influx
2. Circulating monocytes and macrophages extravasate and enter a muscle environment → Pro-inflammatory cytokines Ex: Interferon-γ (IFN-γ) and tumor necrosis factor (TNF)
3. These macrophages are named M1 macrophages to reflect their activation by pro-inflammatory T helper 1

Pro-inflammatory (M1) or pro-regenerative (M2) phenotype



Pro-inflammatory (M1) phenotype macrophage
Pro-regenerative (M2) phenotype macrophage



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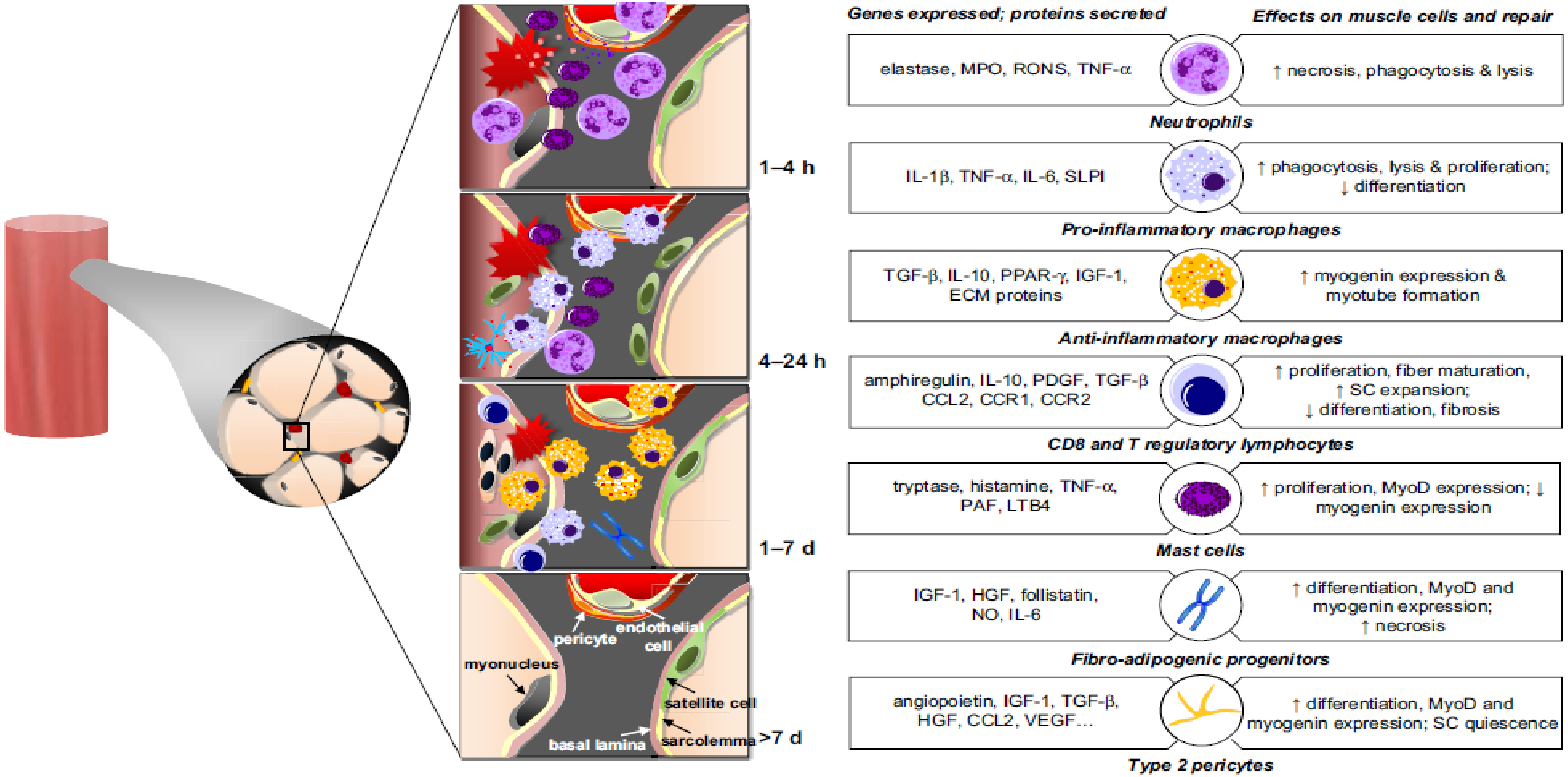
Tidball, J. G. (2017). Regulation of muscle growth and regeneration by the immune system. Nature Reviews Immunology, 17(3), 165-178.

Muscle damage and inflammation during recovery after exercise



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Peake, J. M., Neubauer, O., Della Gatta, P. A., & Nosaka, K. (2017). Muscle damage and inflammation during recovery from exercise. Journal of applied physiology, 122(3), 559-570.

What if the exercise-induced inflammation is inhibited

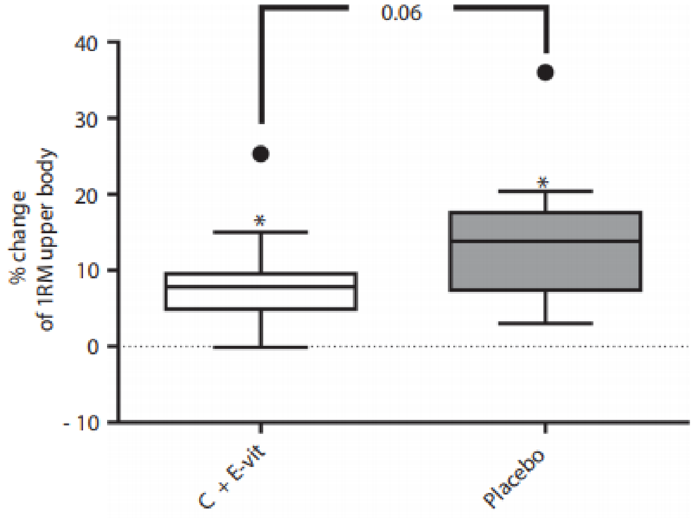
1. Thirty-two recreationally strength-trained men and women
2. 10 weeks (4 sessions/week)
3. Vitamin C and E supplement (1000 mg day−1 and 235 mg day−1)
4. Heavy-load resistance exercise four times per week.

RESULTS: The supplementation did not affect the increase in muscle mass or the acute change in protein synthesis, but it hampered certain strength increases (biceps curl).

Table 4. Body composition before and after the 10-week intervention period

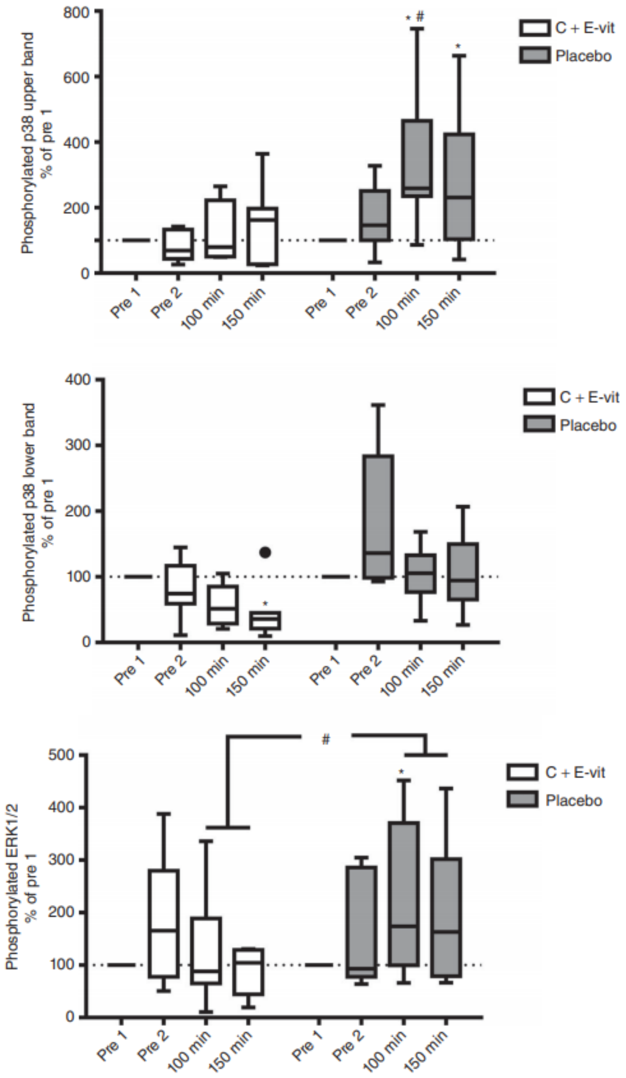
	Vitamin C and E			Placebo		
	Pre	Post	% change	Pre	Post	% change
Body mass (kg)	76.6 ± 11.9	78.2 ± 12.3*	2.2 ± 1.6*	72.8 ± 14.2	73.9 ± 15.0*	1.3 ± 2.7
Fat free mass (kg)	59.7 ± 10.1	60.7 ± 10.3*	1.8 ± 1.6*	59.0 ± 13.2	60.6 ± 14.3*	1.7 ± 1.6*
Bone mineral content (kg)	3.1 ± 0.6	3.1 ± 0.5	0.7 ± 1.5	3.0 ± 0.6	3.0 ± 0.6	0.3 ± 1.5
Lean mass (kg)	56.6 ± 9.6	57.6 ± 9.8*	1.8 ± 1.8*	56.0 ± 12.6	57.5 ± 13.8*	1.9 ± 1.8*
Fat mass (kg)	16.9 ± 4.7	17.5 ± 5.3	3.6 ± 11.9	13.8 ± 3.3	13.9 ± 3.9	−0.3 ± 12.0

Values are means and standard deviations. Within-group changes: *$P \leq 0.01$.



Paulsen, G., Hamarsland, H., Cumming, K. T., Johansen, R. E., Hulmi, J. J., Børsheim, E., ... & Raastad, T. (2014). Vitamin C and E supplementation alters protein signalling after a strength training session, but not muscle growth during 10 weeks of training. *The Journal of physiology*, *592*(24), 5391-5408.

However, according to cellular response



The results are equivocal because we observed an inhibition of the acute protein signalling after a standardized strength exercise session, but there were no significant group differences in muscle protein fractional synthetic rate or muscle growth over 10 weeks of training.

Vitamin C and E supplementation can interfere with the cellular signalling after exercise, such as MAPKs, and ubiquitination, but redundancy in the pathways may overpower most of these effects, and adaptions over time are less affected.

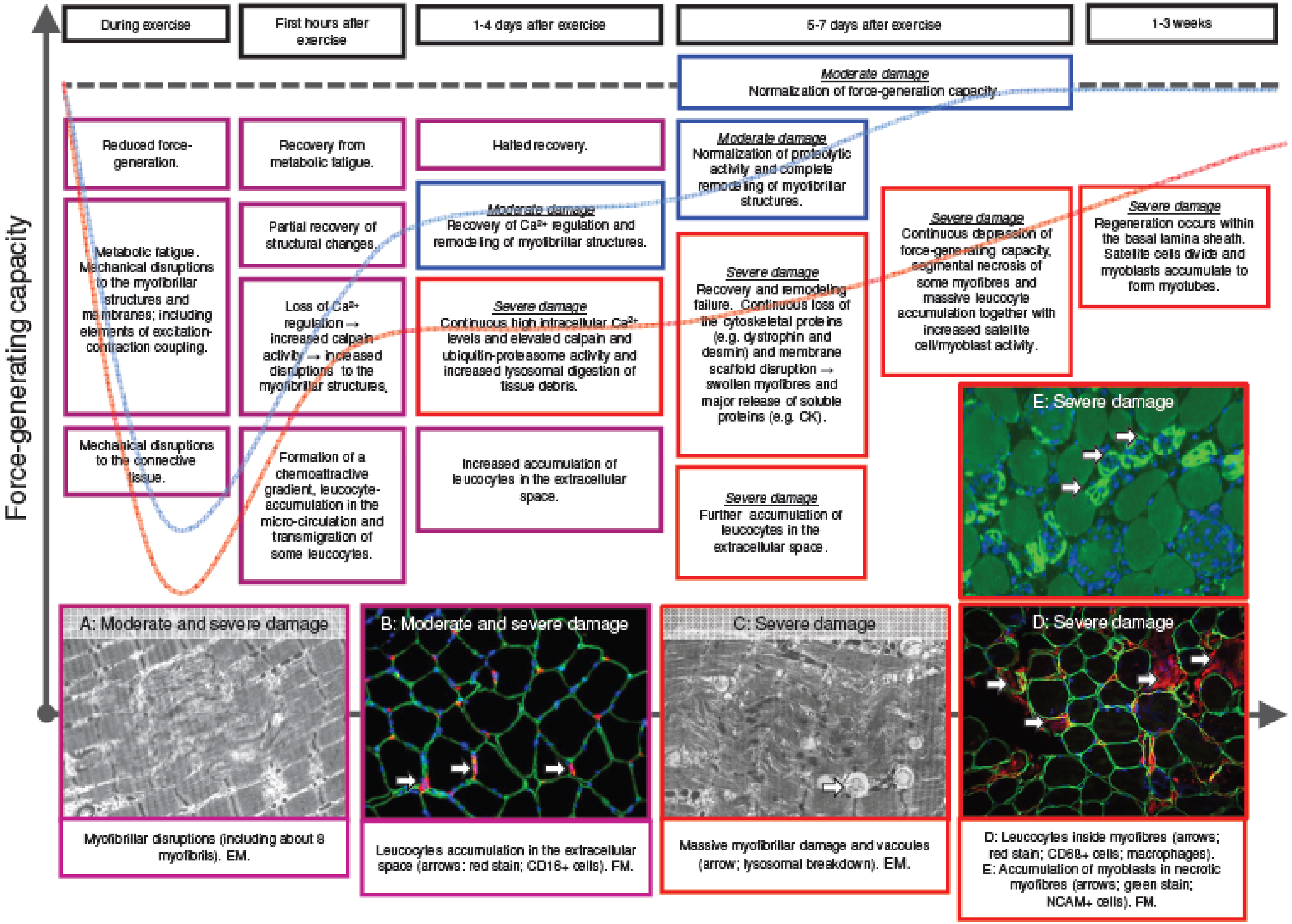
Young, healthy individuals who exercise for improved strength and muscle growth should avoid consuming high dosages of vitamins C and E close to the exercise sessions

Inflammation in skeletal muscle: friend or foe?

- Current evidence suggests that in healthy young individuals, reducing inflammation by use of NSAIDs may interfere with muscle regeneration or hypertrophy. In contrast, NSAIDs may be beneficial under conditions of excessive or prolonged inflammation. For example, in the elderly, low-grade systemic inflammation may contribute to the loss of muscle mass (termed 'sarcopenia'). In this context, NSAIDs may benefit maintenance of muscle mass

Paulsen, G., Ramer Mikkelsen, U., Raastad, T., & Peake, J. M. (2012). Leucocytes, cytokines and satellite cells: what role do they play in muscle damage and regeneration following eccentric exercise?. Exercise immunology review, 18.

A model for central events in the recovery of the force-generating capacity after moderate (blue line) and severe (red line) exercise-induced muscle damage.



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Take home message

- 運動種類及飲食中蛋白質對衛星細胞之影響
- 肌核不會消失/消失速度很慢，以利之後的訓練能快速恢復
- 肌肉內適當的發炎反應是有利的
- 對於年輕族群抗發炎的補充品建議不要在運動前後攝取
- 運動後的恢復時程表 (免疫系統、衛星細胞)，隨著運動種類、強度、個人能力而異 (Specificity of Adaptation)

The history of bodybuilding

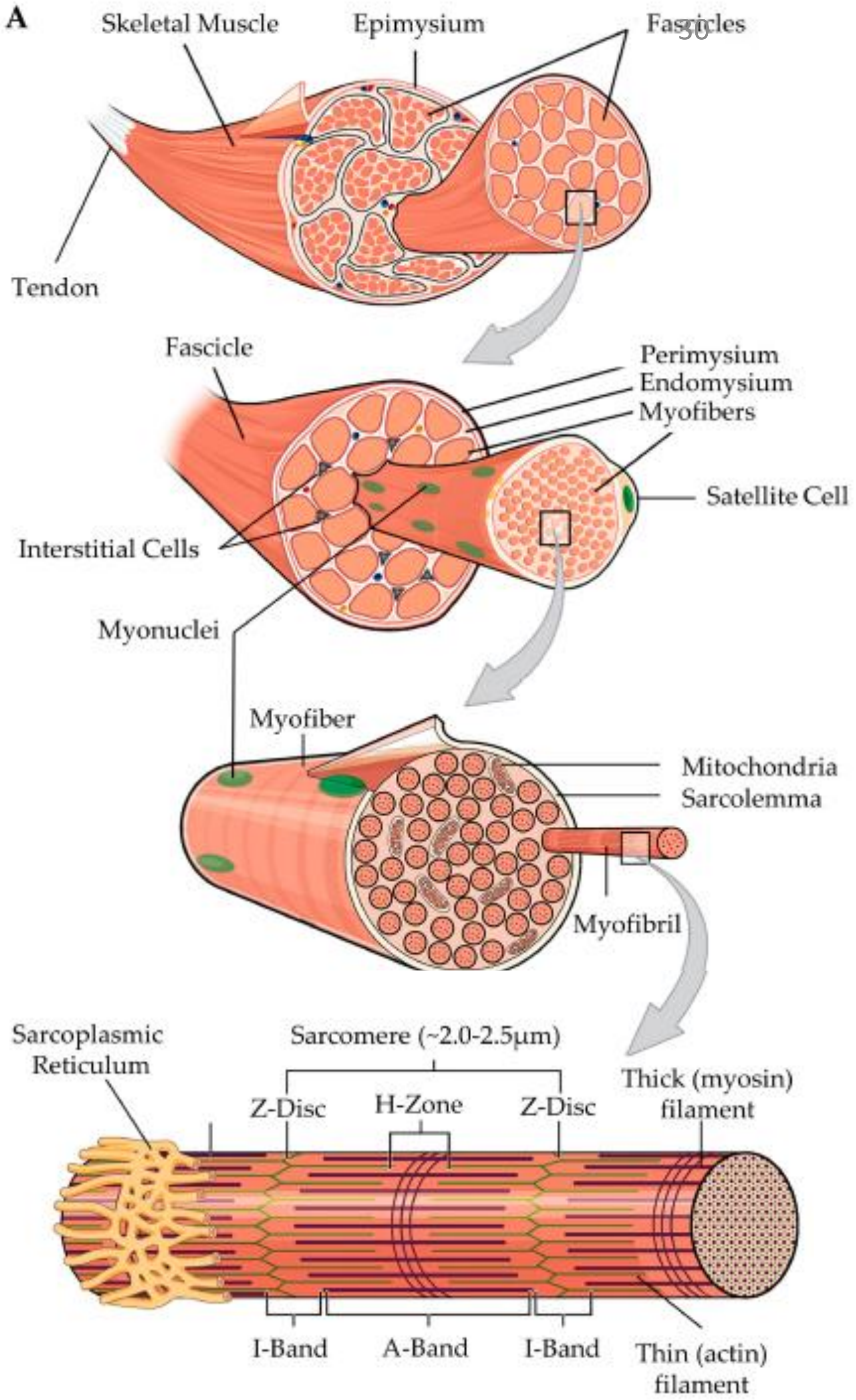
- The Early Period Of 1890-1929

Eugene Sandow, the father of modern bodybuilding   strongman

Hypertrophy:

An increase in the size of muscle tissue

1. Longitudinal or Radial Growth of fascicles
2. Sarcoplasmic hypertrophy
3. Satellite cell



Hyperplasia:

An increase in fiber number (目前較少證據解釋)

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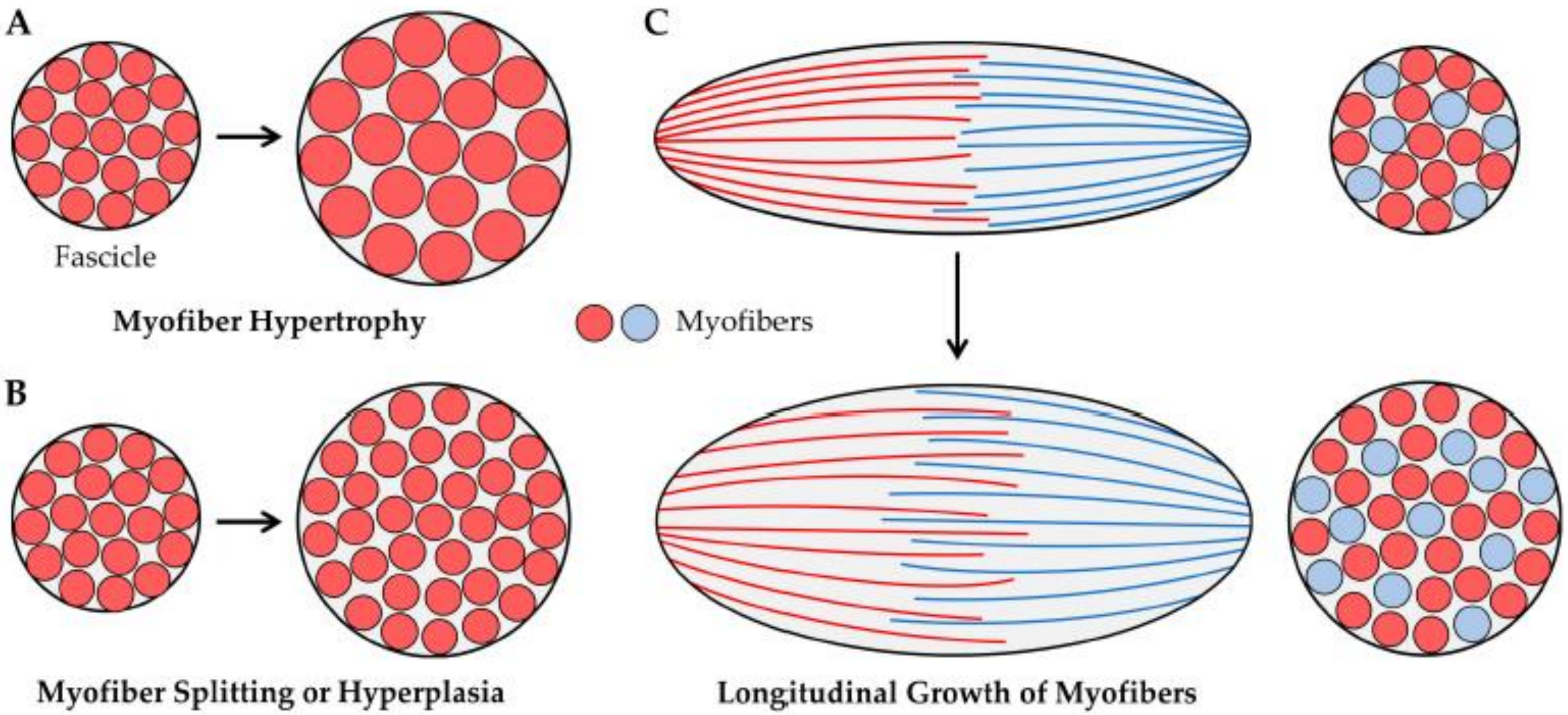
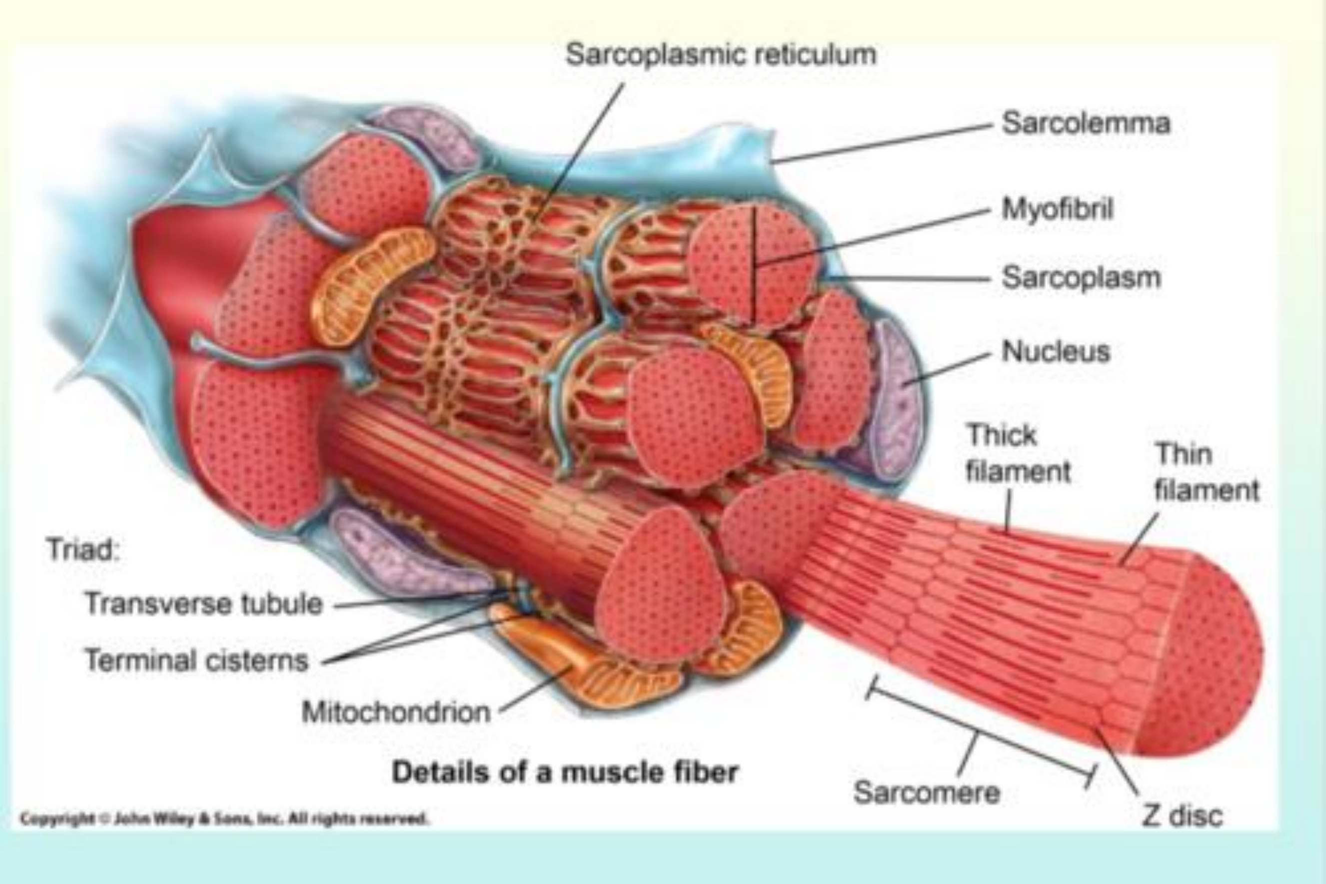
可能發生的肌肉成長

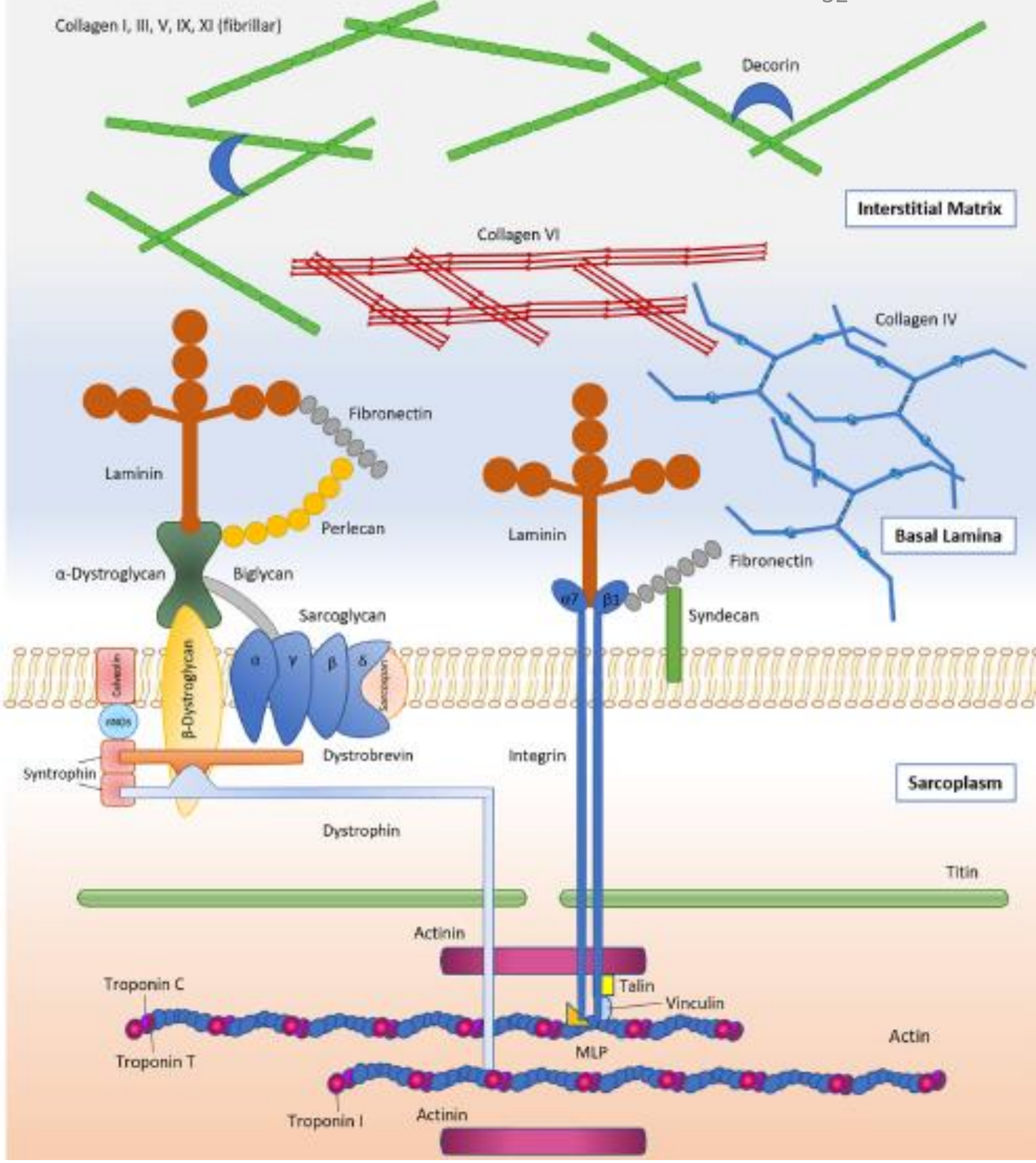


Jorgenson, K. W., Phillips, S. M., & Hornberger, T. A. (2020). Identifying the structural adaptations that drive the mechanical load-induced growth of skeletal muscle: a scoping review. Cells, 9(7), 1658.

Sarcoplasmic hypertrophy

- Sarcoplasm
- Extra Cellular Matrix (ECM)



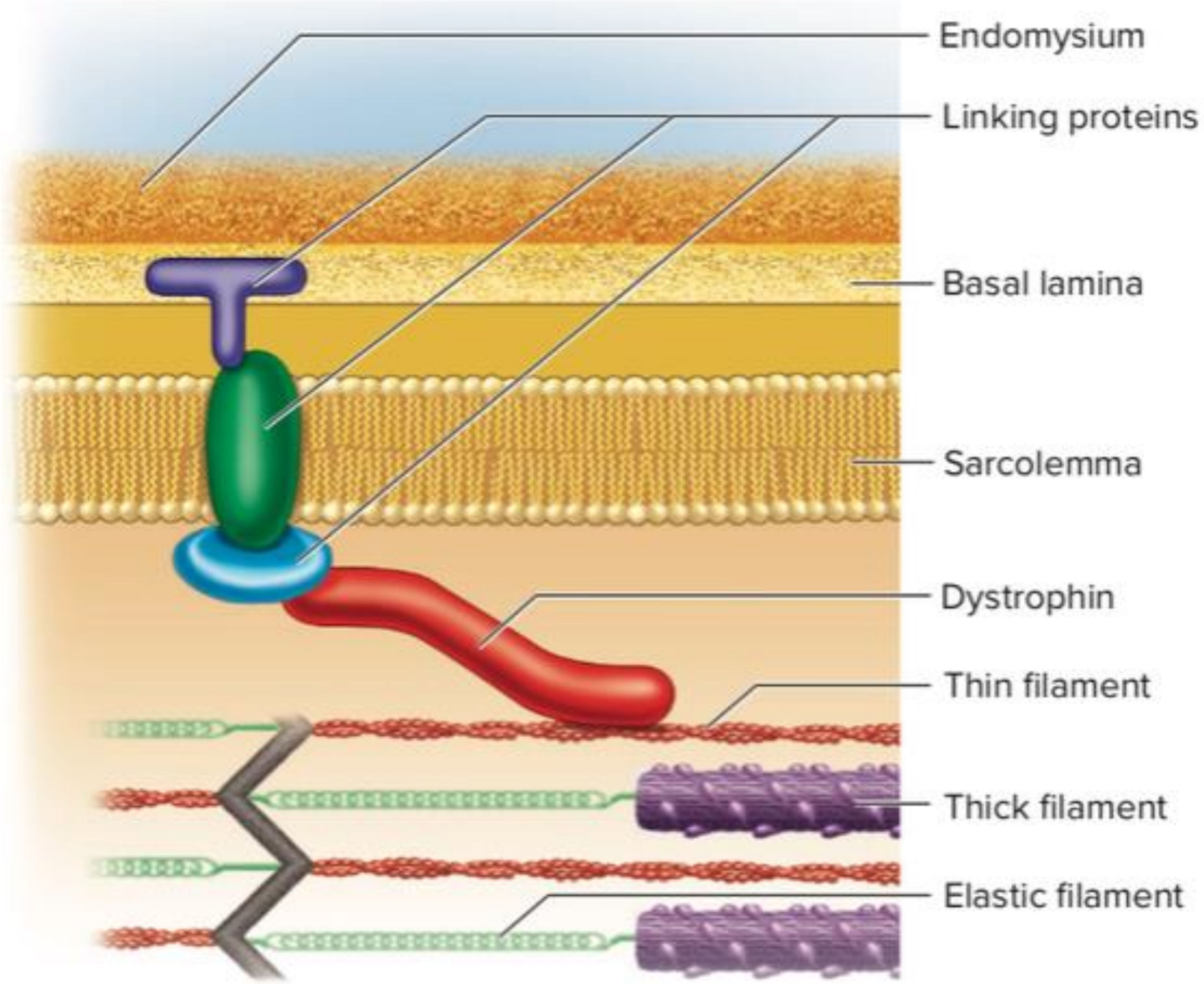


ECM

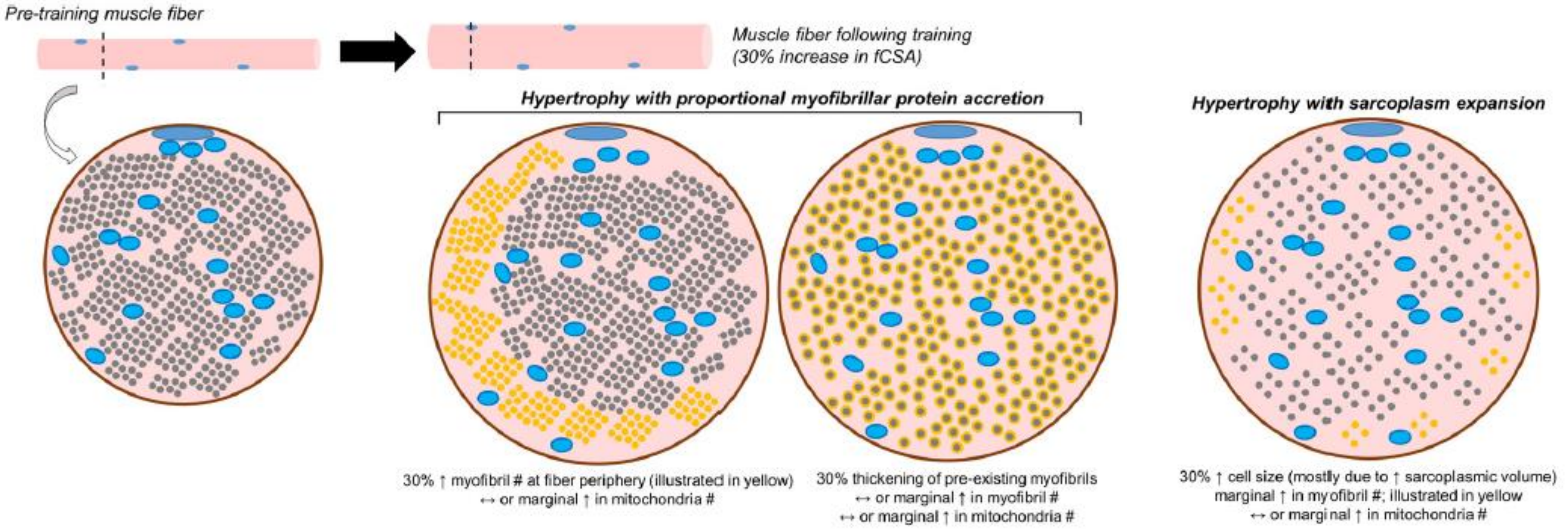
- Extracellular matrix (ECM) consisting of a mesh of collagenous components as well as a mixture of further macromolecules, such as various glycoproteins and proteoglycans.
- The ECM of skeletal muscles is a complex meshwork consisting of collagens, glycoproteins, proteoglycans, and elastin
- Collagens form a network of intramuscular connective tissue (IMCT)
- IMCT: Endomysium, perimysium, epimysium 肌內膜/肌束膜/肌外膜

筋膜Fascial

Sarcolemma and Endomysium
肌纖維膜　　　肌內膜



肌肉肥大示意圖



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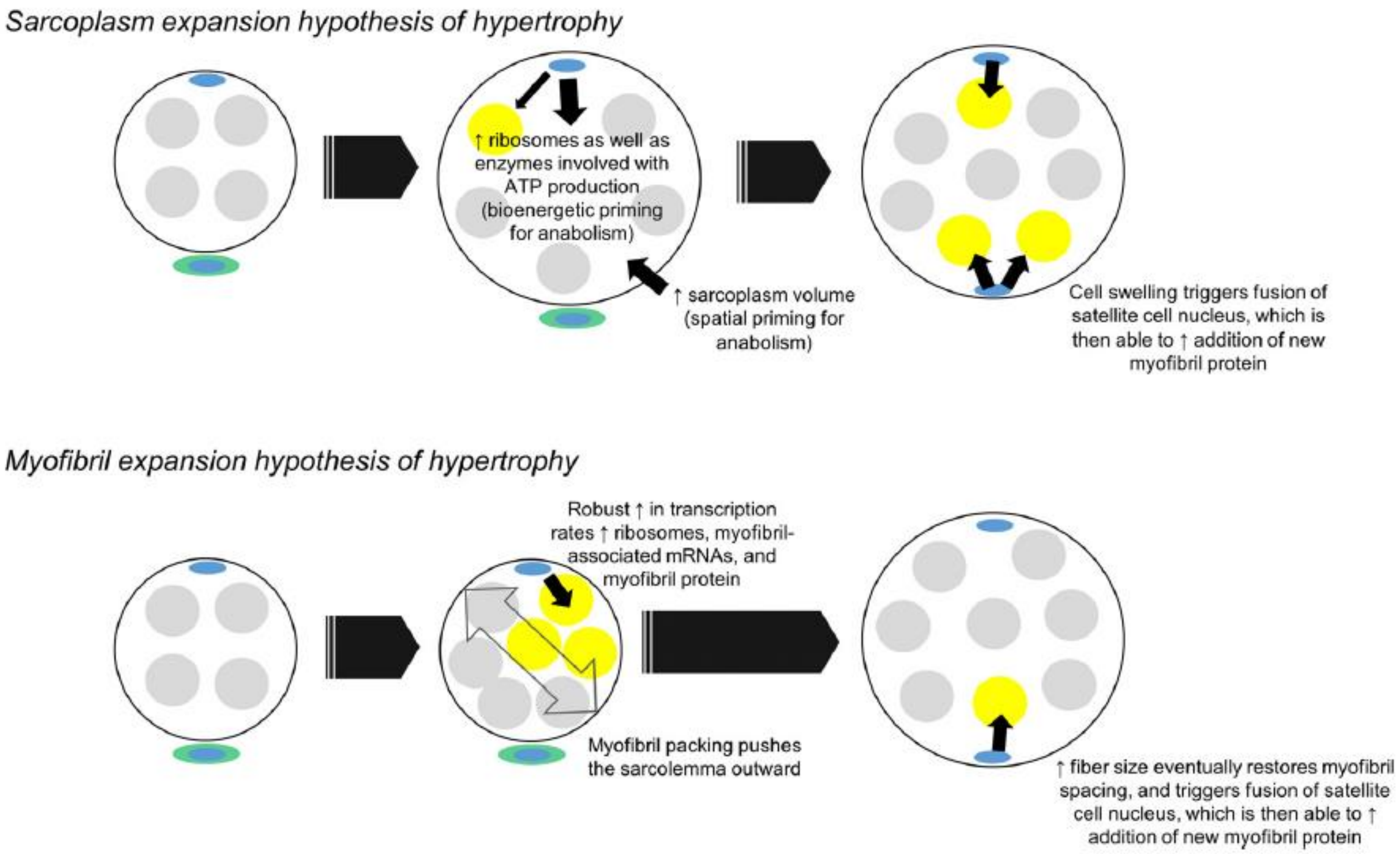
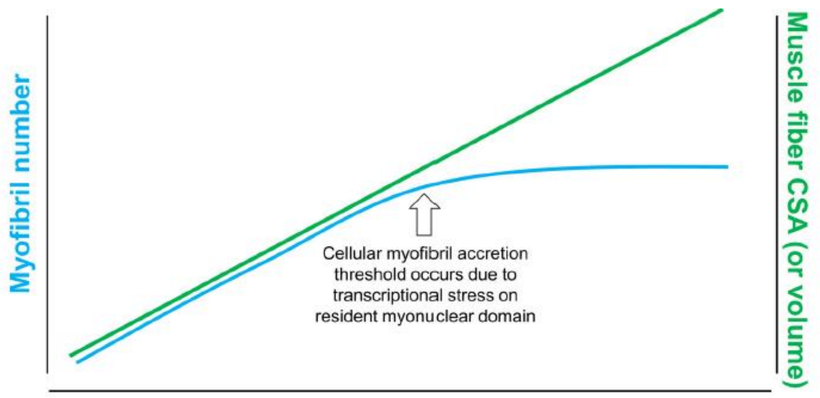
Roberts, M. D., Haun, C. T., Vann, C. G., Osburn, S. C., & Young, K. C. (2020). Sarcoplasmic hypertrophy in skeletal muscle: a scientific "unicorn" or resistance training adaptation?. Frontiers in Physiology, 11.

肌漿、肌纖維肥大先後順序?





Mechanisms contributing to muscle hypertrophy

- Mechanical Tension
- Metabolic Factors (Cell swelling, muscle damage, and increased production of reactive oxygen species)
- Muscle Activation
- Mechanotransduction and growth factors
- Satellite cells
- Hormonal modulation

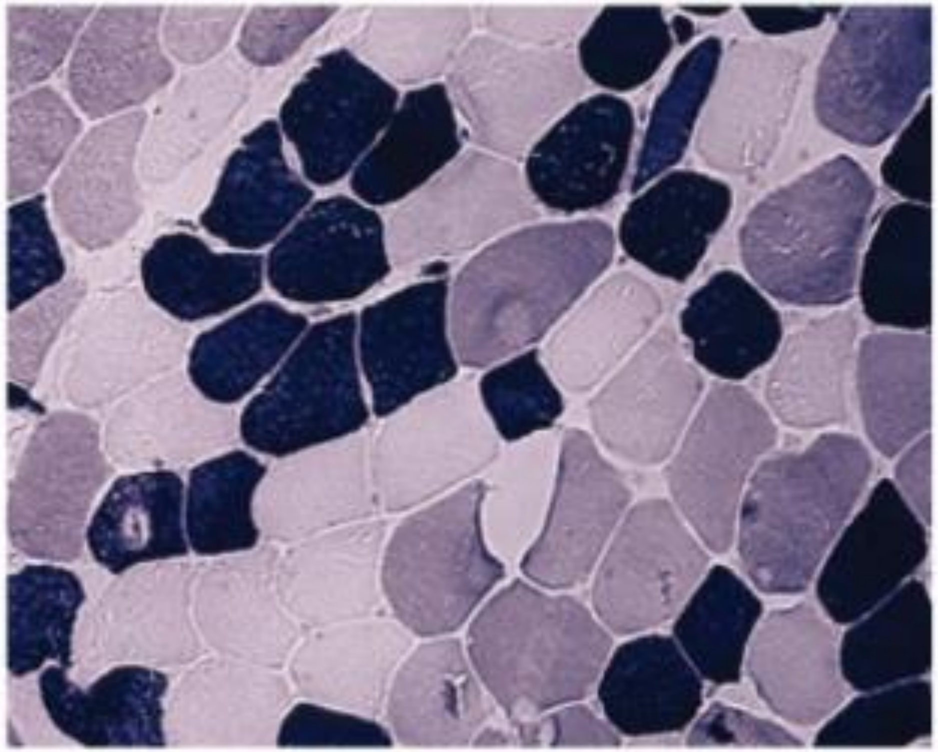
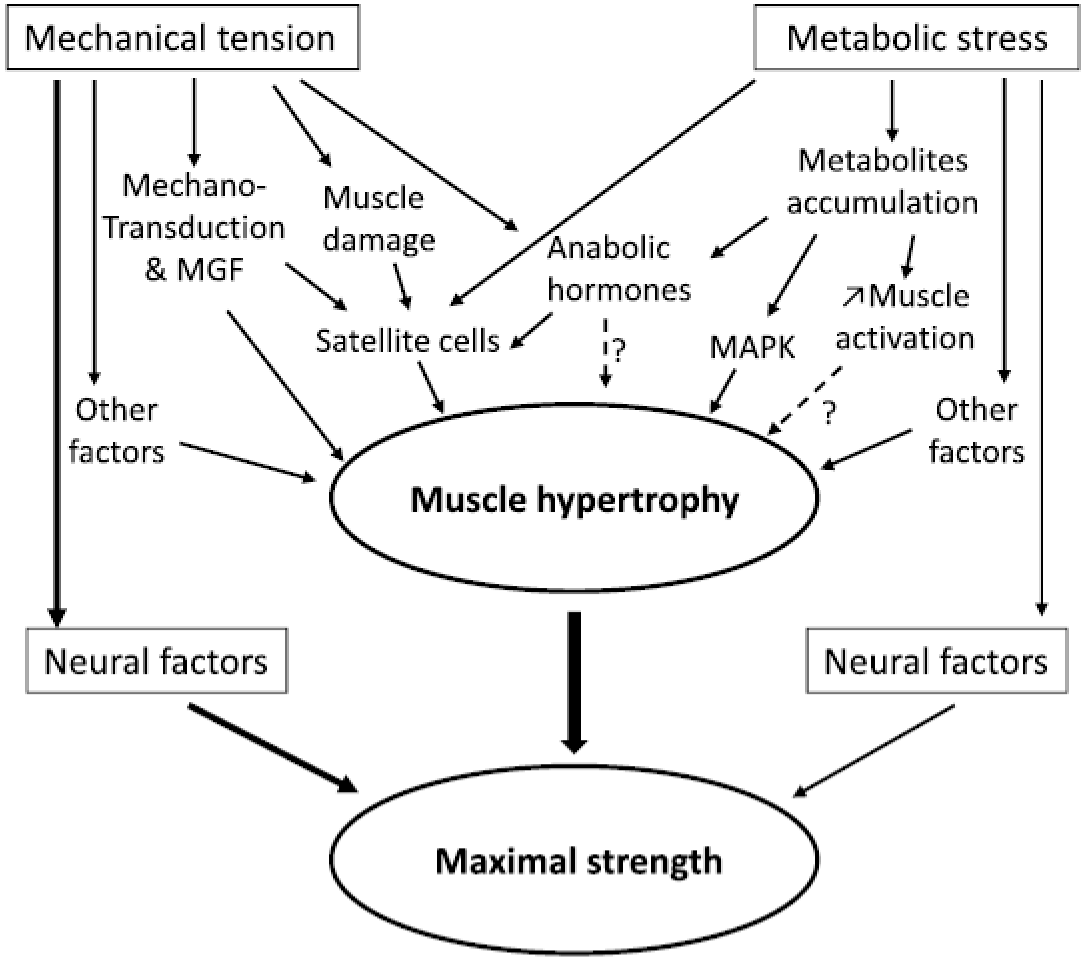
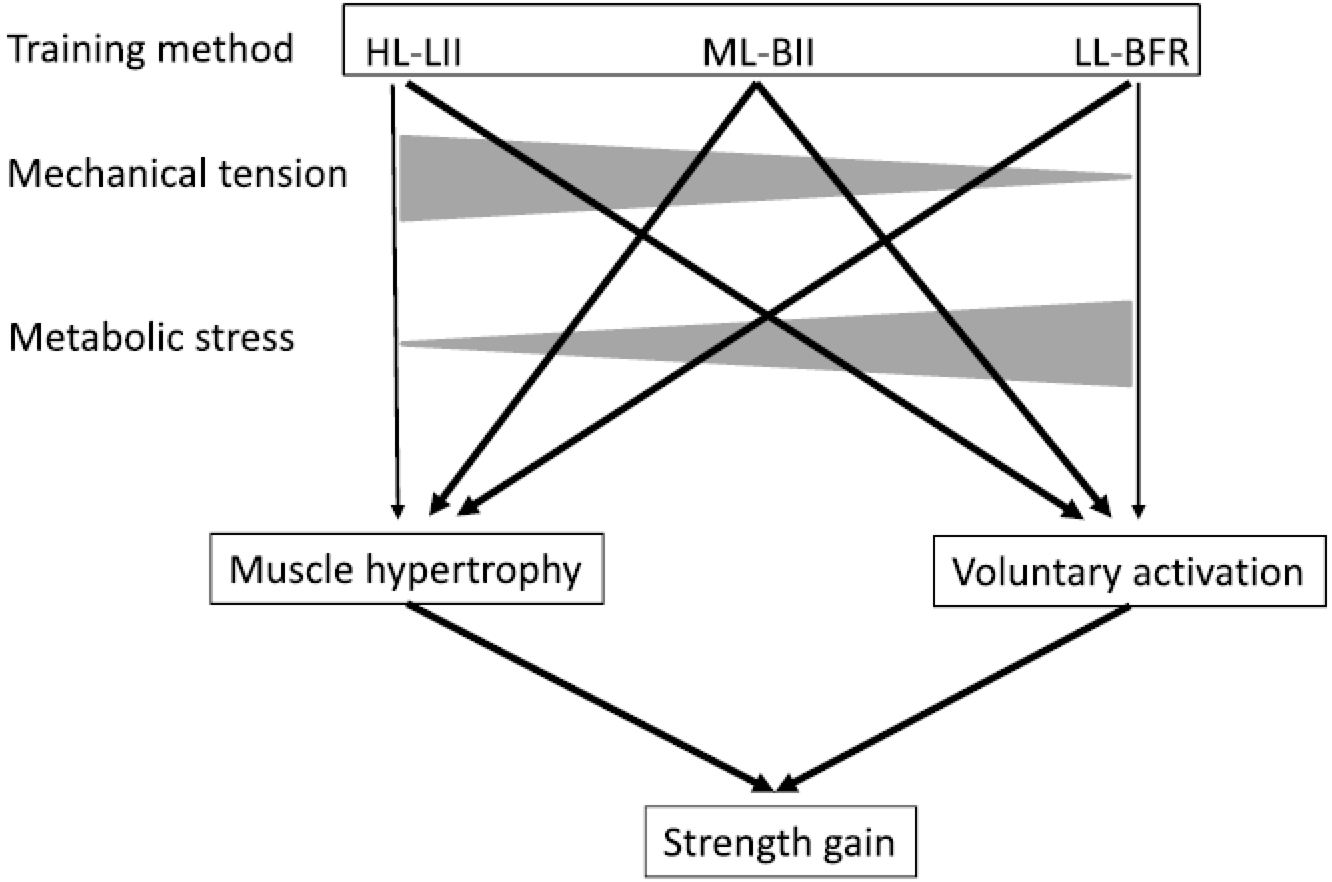


FIGURE 1.4 A photomicrograph showing Type I (black), Type IIa (white), and Type IIx (gray) muscle fibers.

肌肉肥大與力量增加 → 代謝壓力與機械張力





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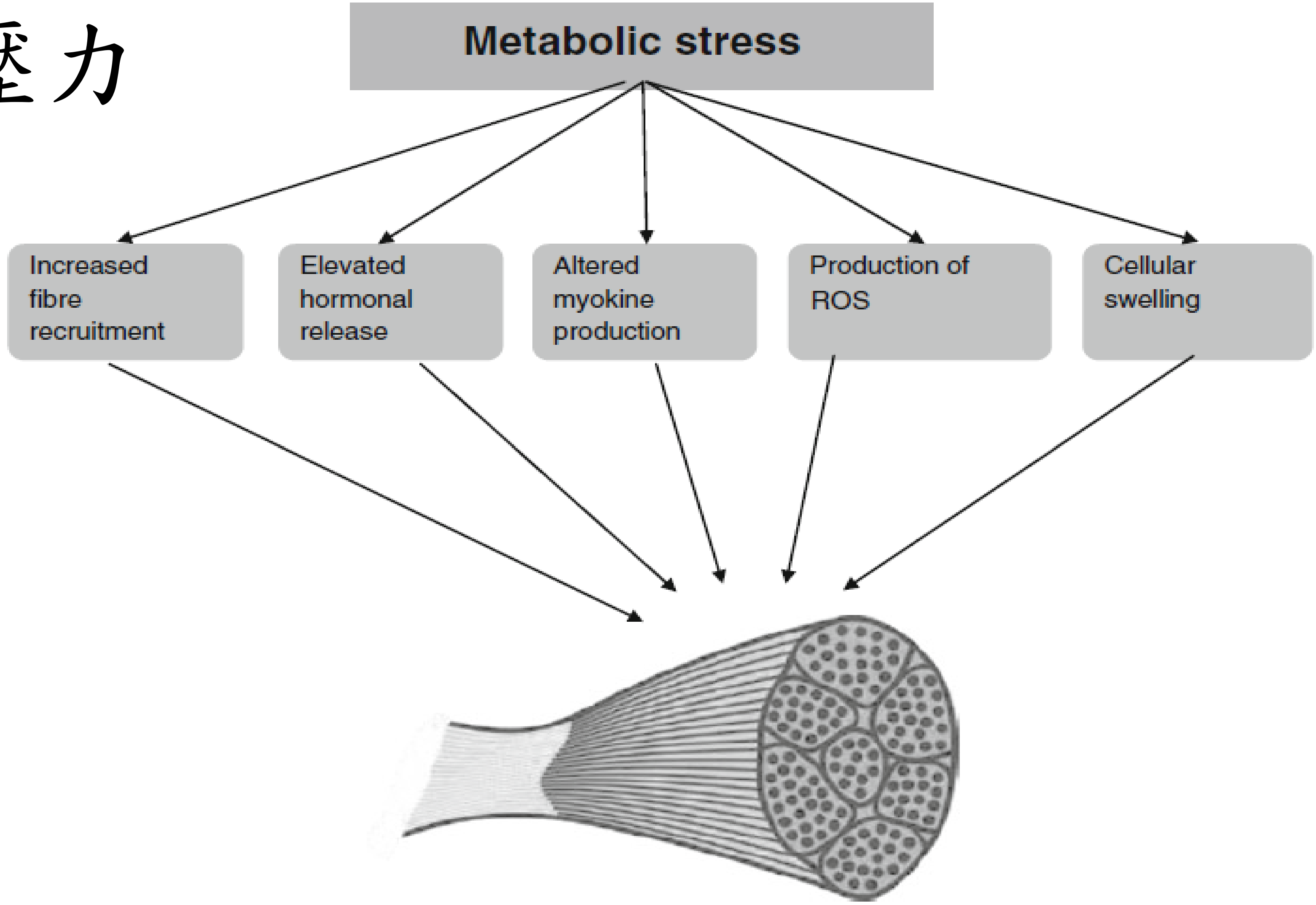
Duchateau, J., Stragier, S., Baudry, S., & Carpentier, A. (2020). Strength Training: In Search of Optimal Strategies to Maximize Neuromuscular Performance. Exercise and Sport Sciences Reviews, 49(1), 2-14.

代謝壓力

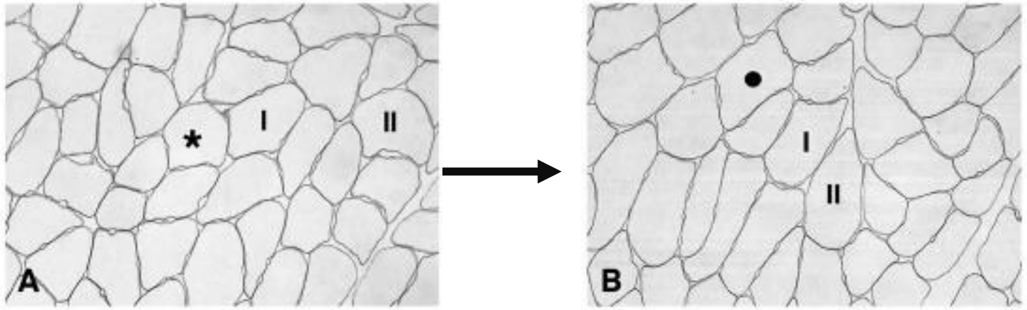


Schoenfeld, B. J. (2013). Potential mechanisms for a role of metabolic stress in hypertrophic adaptations to resistance training. Sports medicine, 43(3), 179-194.

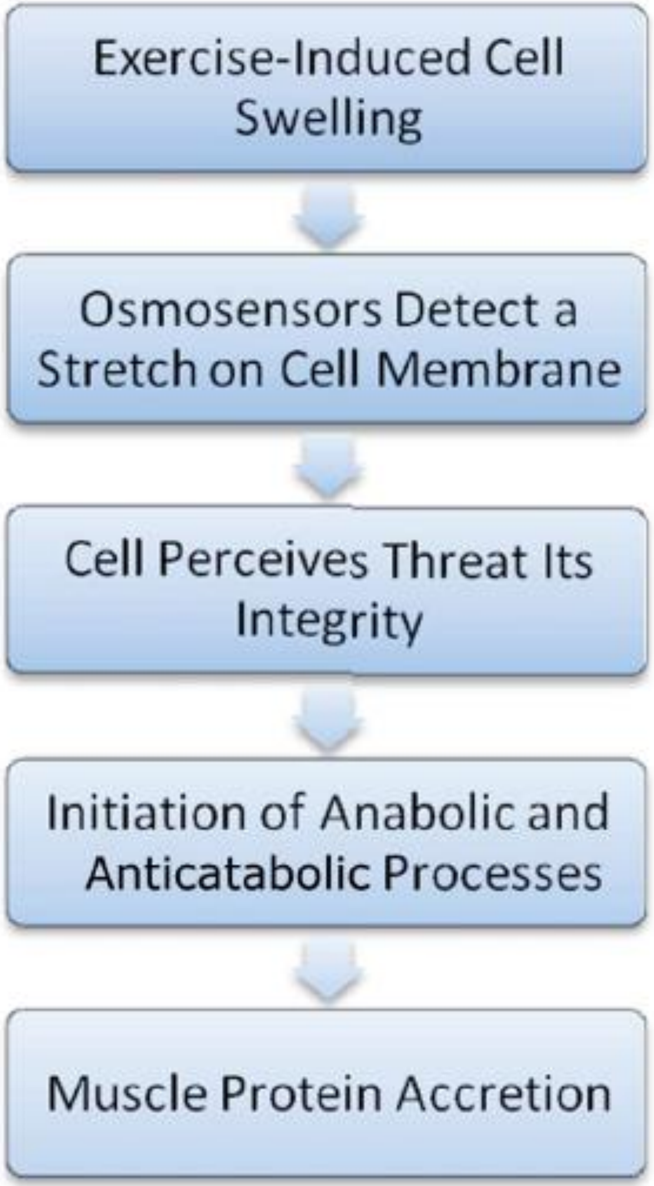
Cell swelling

During intense muscular contractions, the veins taking blood out of working muscles are compressed, whereas arteries continue to deliver blood into the working muscles, thereby creating an increased concentration of intramuscular blood plasma.

Post exercise – cellular hydration



Individuals seeking maximal hypertrophy should consider dedicating a component of their training sessions toward “pump” training, ideally after heavier strength work.



Schoenfeld, B. J., & Contreras, B. (2014). The muscle pump: potential mechanisms and applications for enhancing hypertrophic adaptations. Strength & Conditioning Journal, 36(3), 21-25.

Venous blood flow restriction training may be induced by muscle cell swelling

Loenneke, J., Fahs, C. A., Rossow, L. M., Abe, T., & Bemben, M. G. (2012). The anabolic benefits of venous blood flow restriction training may be induced by muscle cell swelling. Medical hypotheses, 78(1), 151-154.

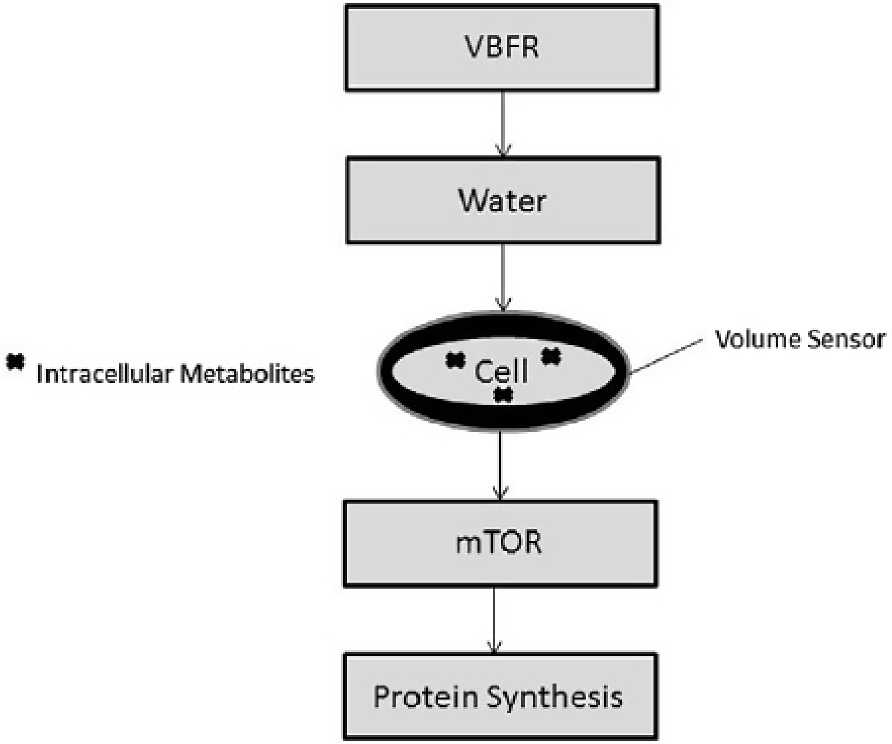


Fig. 1. A hypothetical model showing that venous blood flow restriction (VBFR) alone can induce muscle cell swelling which is detected by an intrinsic volume sensor, leading to activation of the mammalian target of rapamycin (mTOR). VBFR alone results in minimal increases of intracellular metabolites.

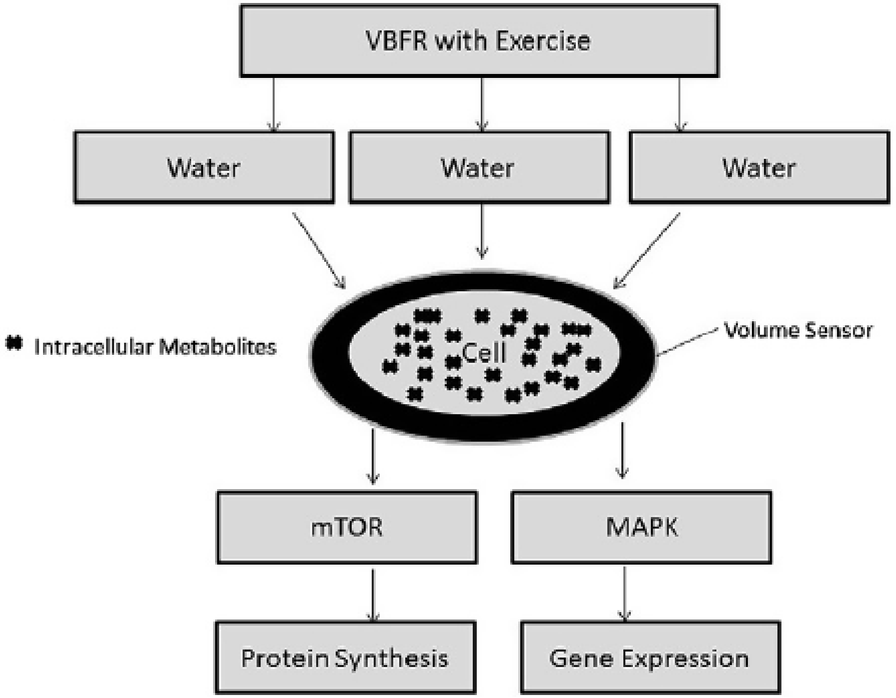


Fig. 2. A hypothetical model showing that venous blood flow restriction (VBFR) with exercise can induce greater increases of intracellular metabolites and muscle cell swelling than VBFR without exercise. This increase in muscle cell swelling which is detected by an intrinsic volume sensor results in concurrent activation of the mammalian target of rapamycin (mTOR) and mitogen-activated protein-kinase (MAPK) pathways leading to greater muscle adaptation.

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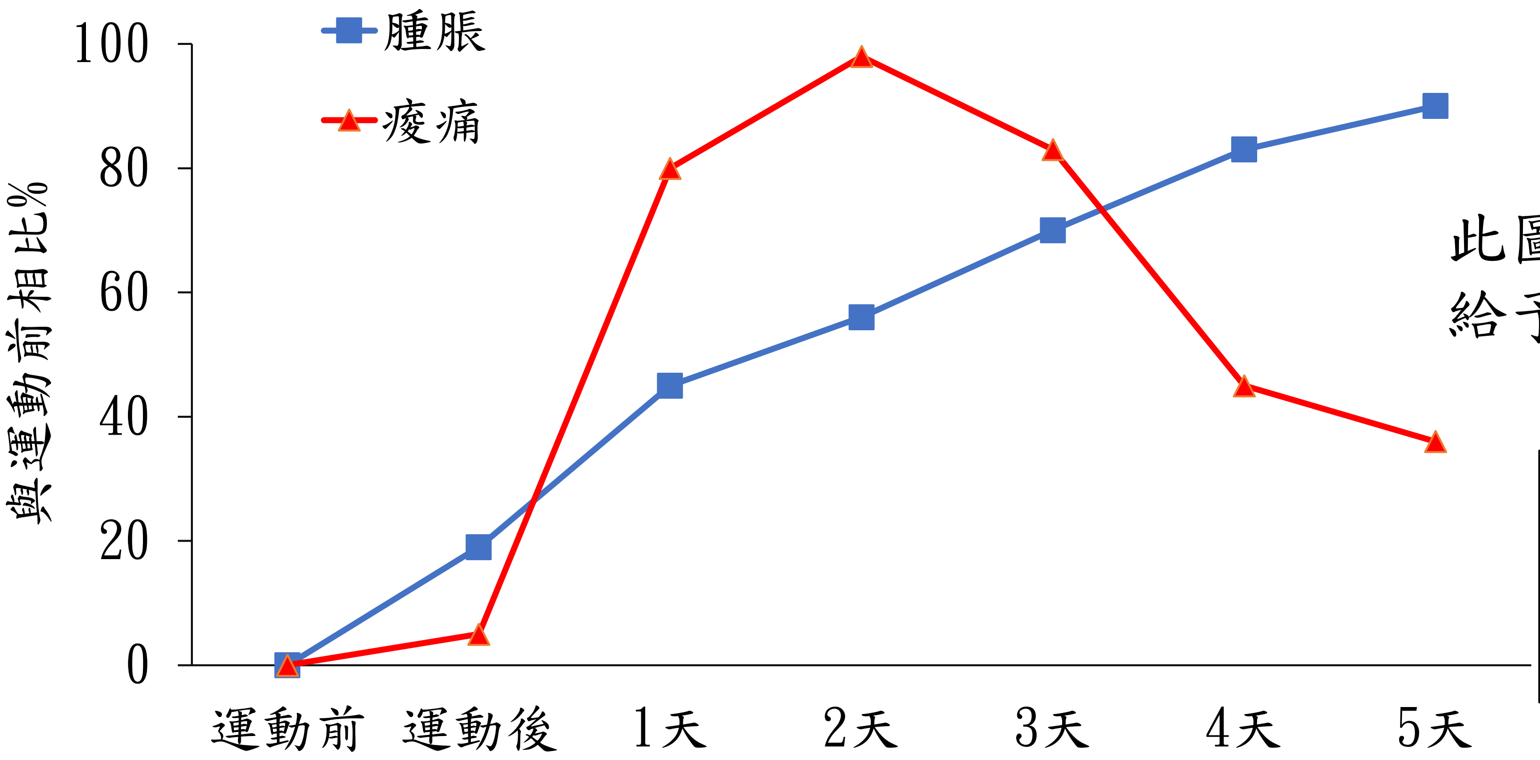
Rolnick, Nicholas DPT, MS1; Schoenfeld, Brad J. PhD, CSCS, CSPS, FNSCA2 Blood Flow Restriction Training and the Physique Athlete: A Practical Research-Based Guide to Maximizing Muscle Size, Strengt and Conditioning Journal: October 2020 - Volume 42 - Issue 5 - p 22-36

肌肉腫脹與痠痛感



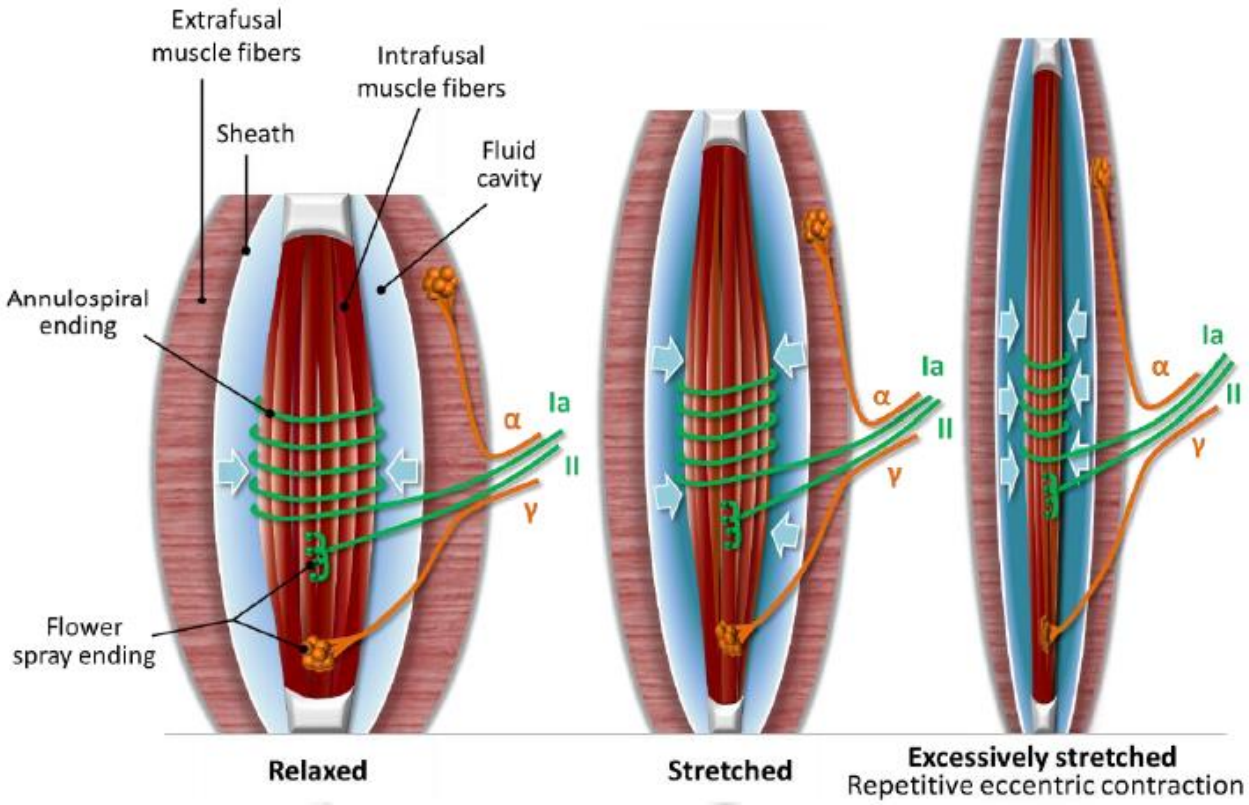
此圖來自286位沒運動習慣的年輕男性
給予30次最大離心運動的二頭彎舉

肌肉腫脹高峰：4-5天
肌肉痠痛：2天(DOMS)

Yu, J. G., Liu, J. X., Carlsson, L., Thornell, L. E., & Stål, P. S. (2013). Re-evaluation of sarcolemma injury and muscle swelling in human skeletal muscles after eccentric exercise. PloS one, 8(4), e62056.

Peake, J. M., Neubauer, O., Della Gatta, P. A., & Nosaka, K. (2017). Muscle damage and inflammation during recovery from exercise. Journal of applied physiology, 122(3), 559-570.

DOMS表示肌肉成長嗎?



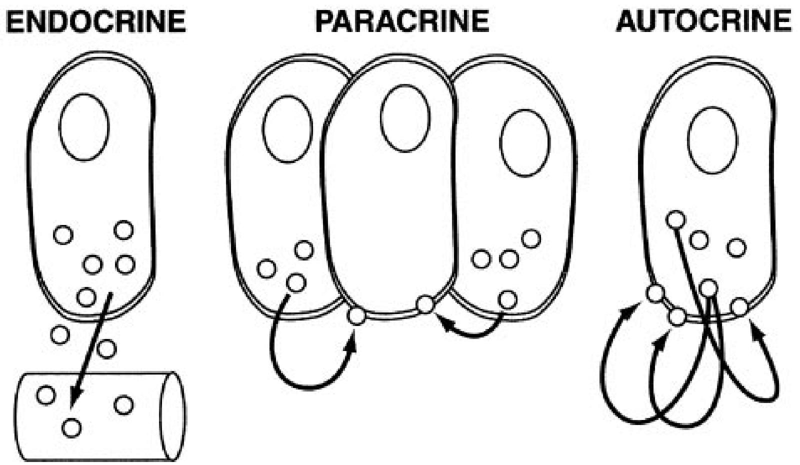
■ **延遲性肌肉痠痛(DOMS)：**
運動後6-8小時開始有感，最痛為運動後48小時

理由	延遲性肌肉痠痛部分意味著肌肉損傷 所以可以代表肌肉損傷之後的成長
但是	痠痛並非是良好的成長指標
原因	並非與肌肉損傷有高度的相關性，兩者 發生之時間軸也不一致
注意	過多的痠痛也不是件好事， 影響到恢復速度和之後的訓練

結論： 沒錯！ 痠痛=有練到
但並非完全等於肌肉成長

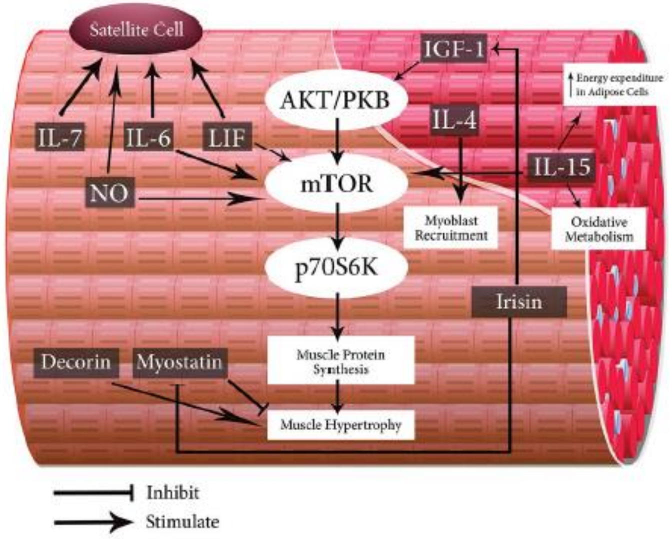
Sonkodi, B., Berkes, I., & Koltai, E. (2020). Have We Looked in the Wrong Direction for More Than 100 Years? Delayed Onset Muscle Soreness Is, in Fact, Neural Microdamage Rather Than Muscle Damage. Antioxidants, 9(3), 212.

Schoenfeld, B. J., & Contreras, B. (2013). Is postexercise muscle soreness a valid indicator of muscular adaptations?. Strength & Conditioning Journal, 35(5), 16-21.



Cytokines 細胞激素

- Polypeptides and proteins.
- Target tissue→ Autocrine (自分泌), Paracrine (旁分泌) Endocrine (內分泌)
- Myokine 肌肉激素 secreted by skeletal muscle fibers.
- The extent of the myokine release response after muscular contraction varies with the intensity, mode, and volume of exercise an individual performs.



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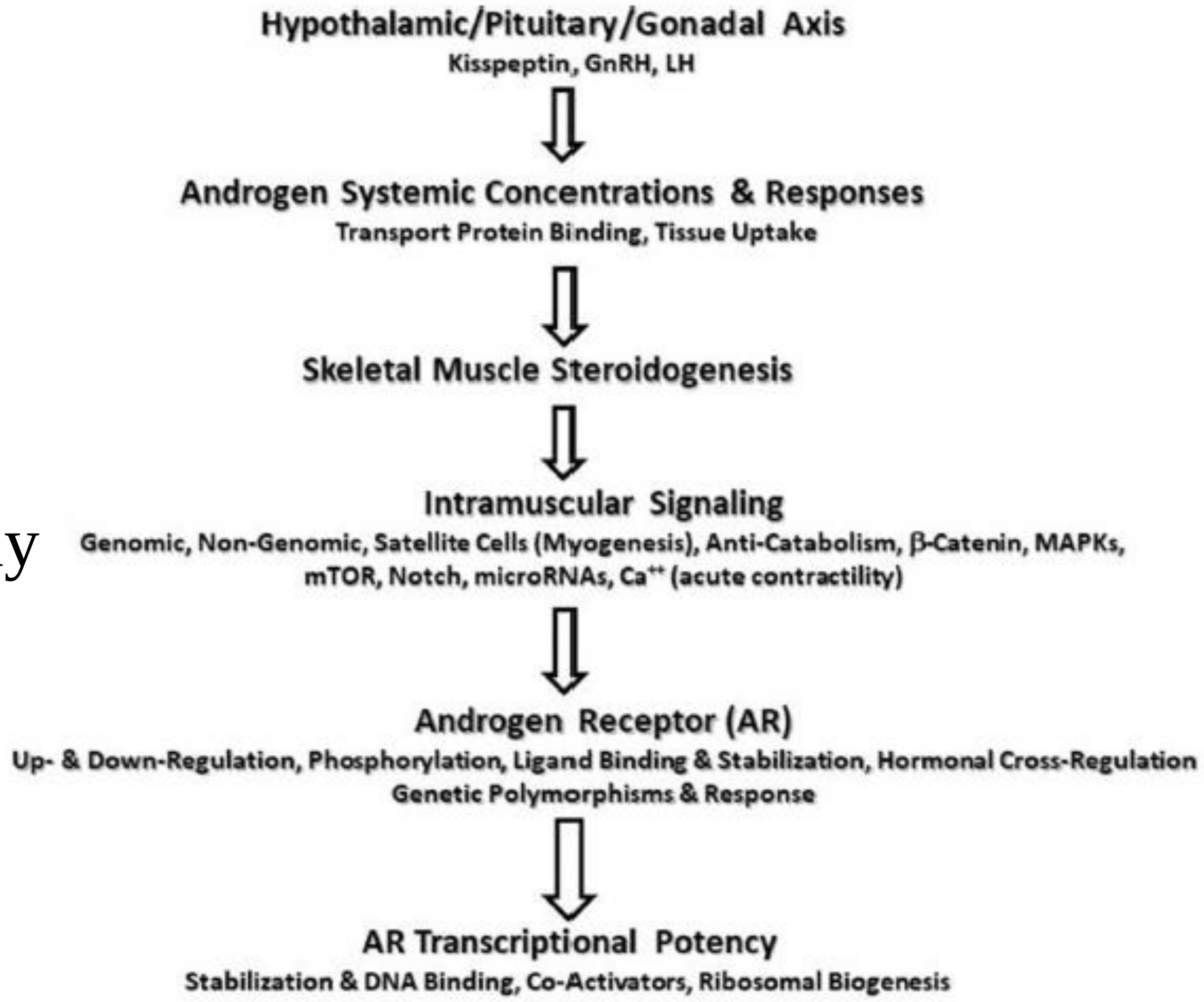
Anabolic giants

- Three key hormones

1. Testosterone
2. The growth hormone superfamily
3. Insulin-like growth factor superfamily

- Glucocorticoid (ex: cortisol)

Homeostatic mechanisms controlled by the endocrine system (acute or chronic)

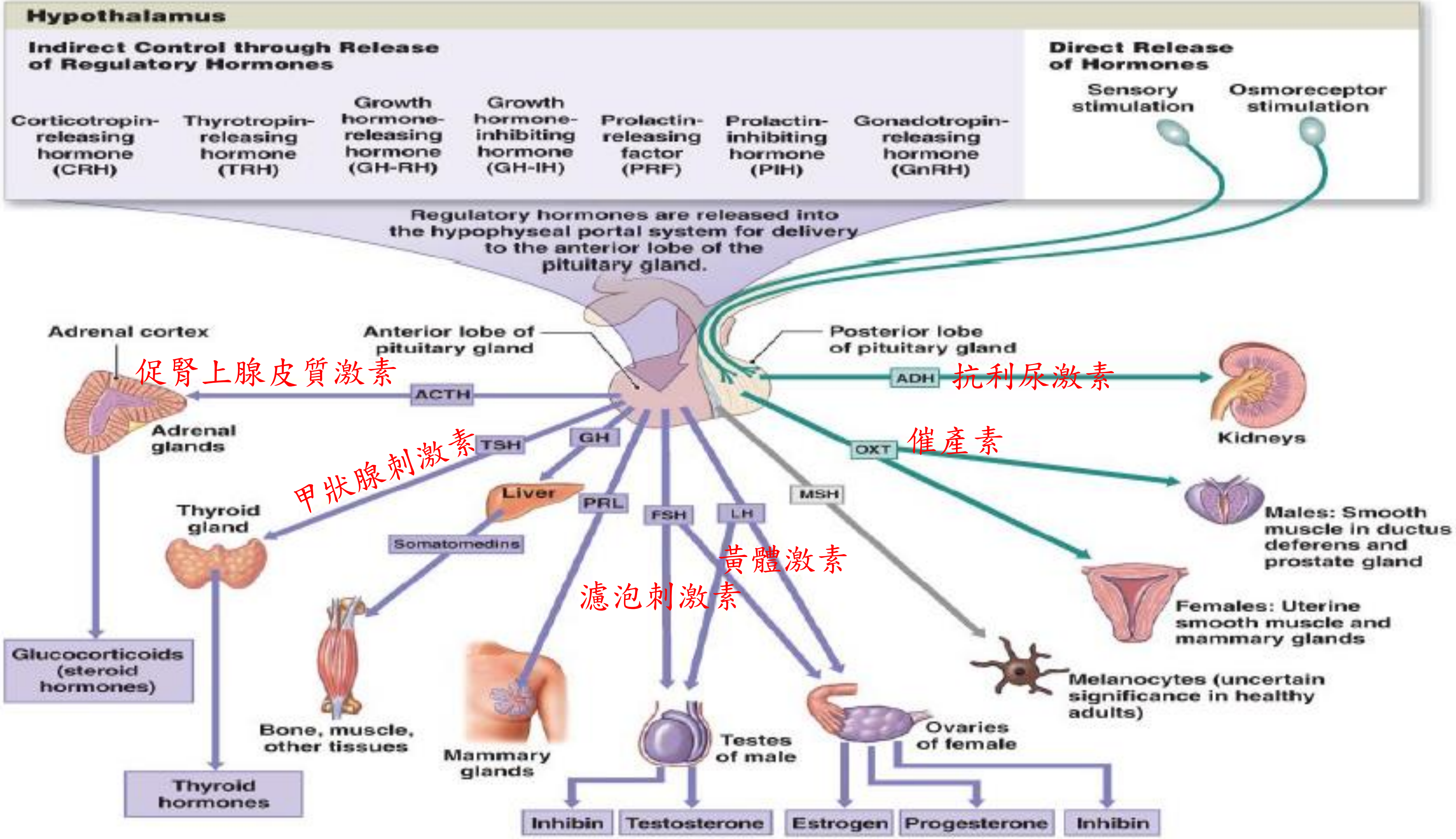


Kraemer, W. J., Ratamess, N. A., Hymer, W. C., Nindl, B. C., & Fragala, M. S. (2020). Growth Hormone (s), Testosterone, Insulin-Like Growth Factors, and Cortisol: Roles and Integration for Cellular Development and Growth With Exercise. Frontiers in Endocrinology, 11, 33.

Endocrine axes

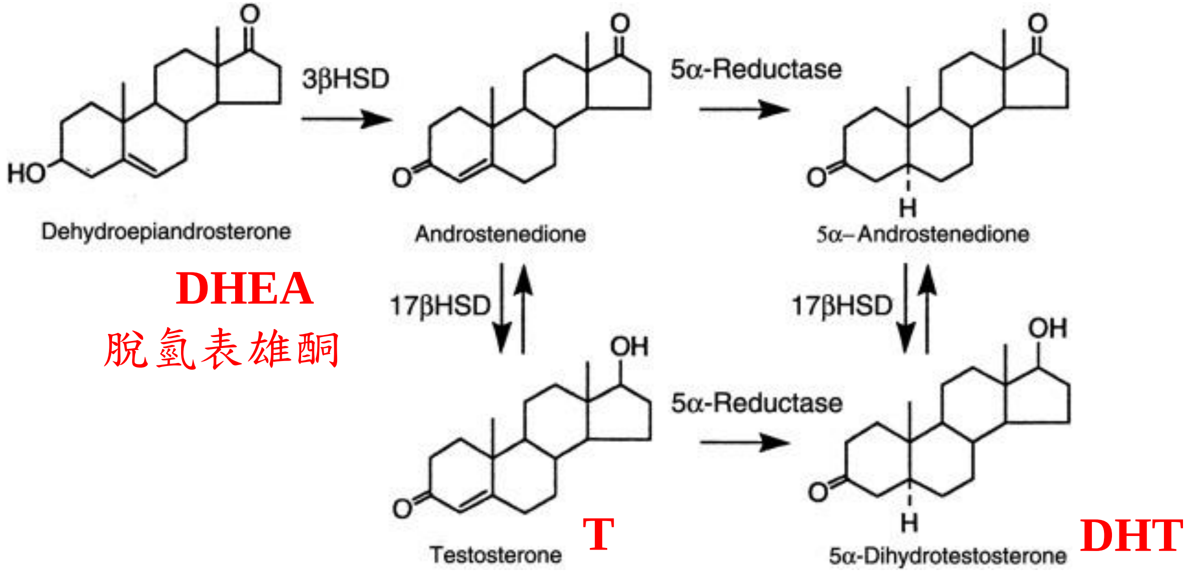
Hypothalamic–pituitary–adrenal axis - HPA axis
下視丘-腦下垂體-腎上腺
Hypothalamic–pituitary–thyroid axis - HPT axis
下視丘-腦下垂體-甲狀腺
Hypothalamic–pituitary–gonadal axis - HPG axis
下視丘-腦下垂體-性腺(男生/女生)

An overview of the relationships between hypothalamic and pituitary hormones, and some effects of pituitary hormones on target tissues



Testosterone (HPG Axis)

- Anabolic-androgenic steroid hormone
- Androgen receptors (AR) in skeletal muscle
- Dihydrotestosterone 二氫睪固酮
- Some T is converted to the more potent DHT via 5a reductase. This enzyme is present in skeletal muscle and circulating DHT can diffuse into muscle cells and bind to ARs with higher affinity than T.



萊氏細胞；睪丸間質內細胞
Leydig cell

- The primary androgen, T, is synthesized from cholesterol and other precursors in the Leydig cells of the testes (>95% in men with some adrenal contributions) under control of the hypothalamic-anterior pituitary-gonadal axis where gonadotropin releasing hormone (GnRH) stimulates the release of luteinizing hormone (LH) from gonadotrophs.
- Testosterone is released into circulation and transported mostly by sex hormone-binding globulin (SHBG) (44–60%) and loosely-bound to albumin or other proteins.
- At the target tissue, testosterone disassociates from binding protein and crosses the cell membrane in order to bind to the intracellular androgen receptor.

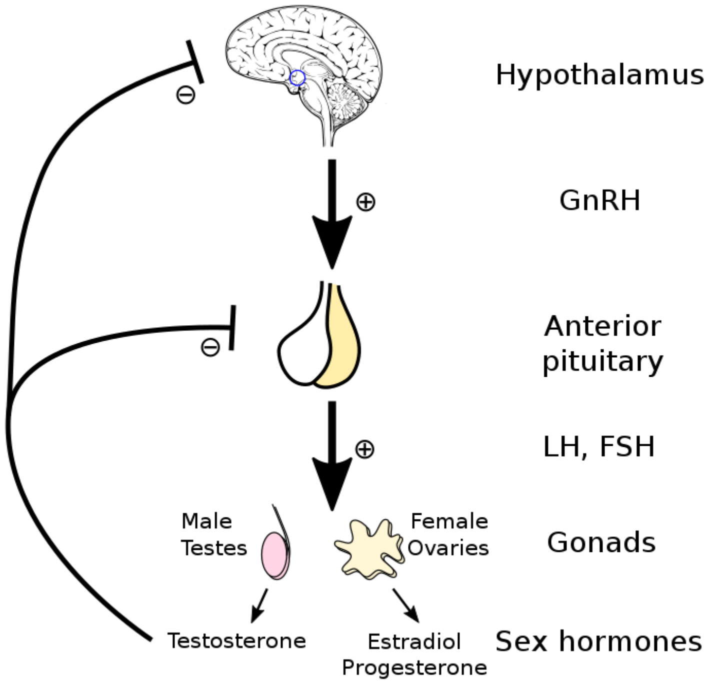


Image was cited from Wikipedia

In women

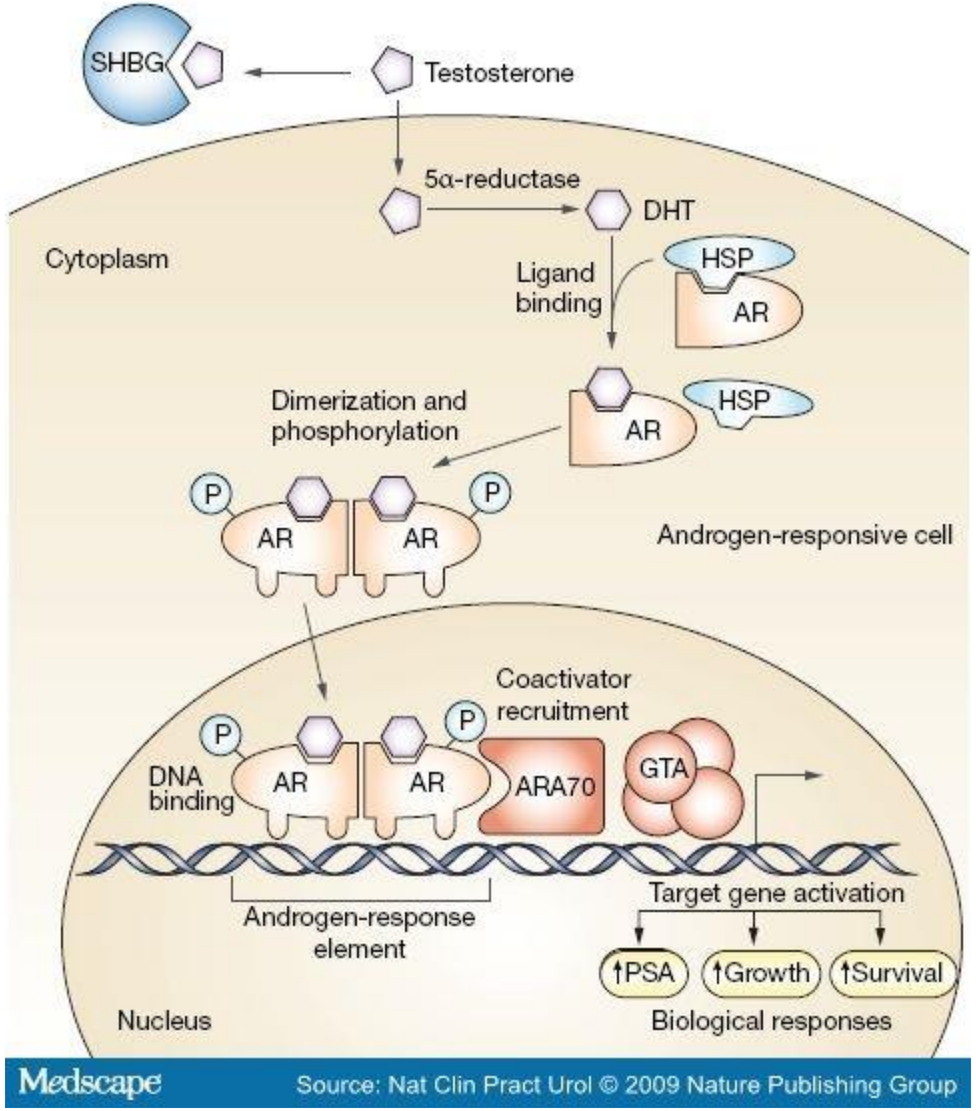
- Ovarian and adrenal production of androgens are major sources. Skeletal muscle contains the enzymes and produces small amounts of androgens.
- Skeletal muscle steroidogenesis from DHEA: Steroidogenic enzyme content and T Concentrations in skeletal muscle are similar between men and women.

Androgen receptor

The concentration of ARs in skeletal muscle depends on the muscle fiber type, sex, training status, and androgen concentrations.

Muscle Androgen Receptor Content but Not Systemic Hormones Is Associated With Resistance Training-Induced Skeletal Muscle Hypertrophy in Healthy, Young Men

*Robert W. Morton[1], Koji Sato[2], Michael P. B. Gallaugher[3], Sara Y. Oikawa[1], Paul D. McNicholas[3], Satoshi Fujita[4] and Stuart M. Phillips[1]**



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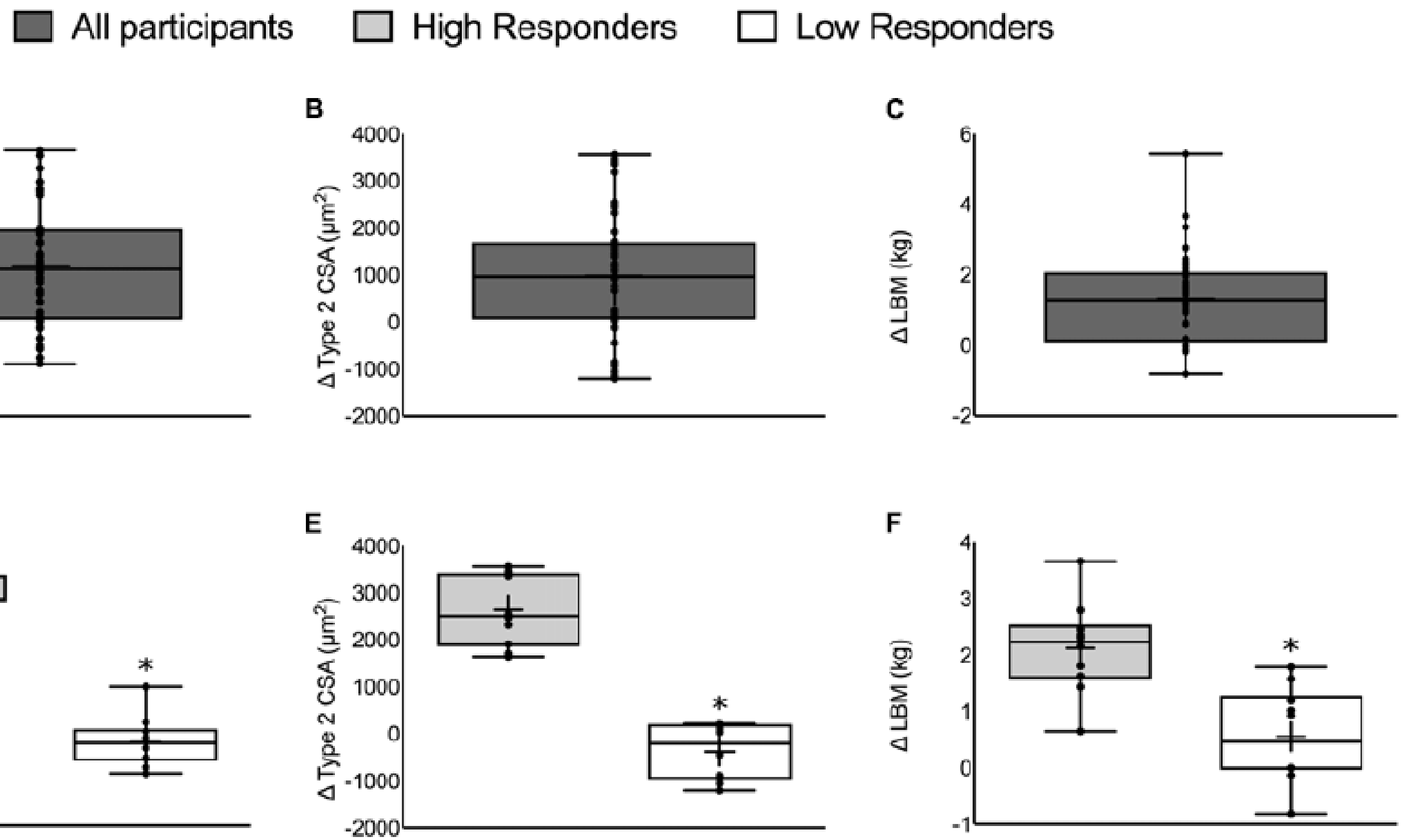
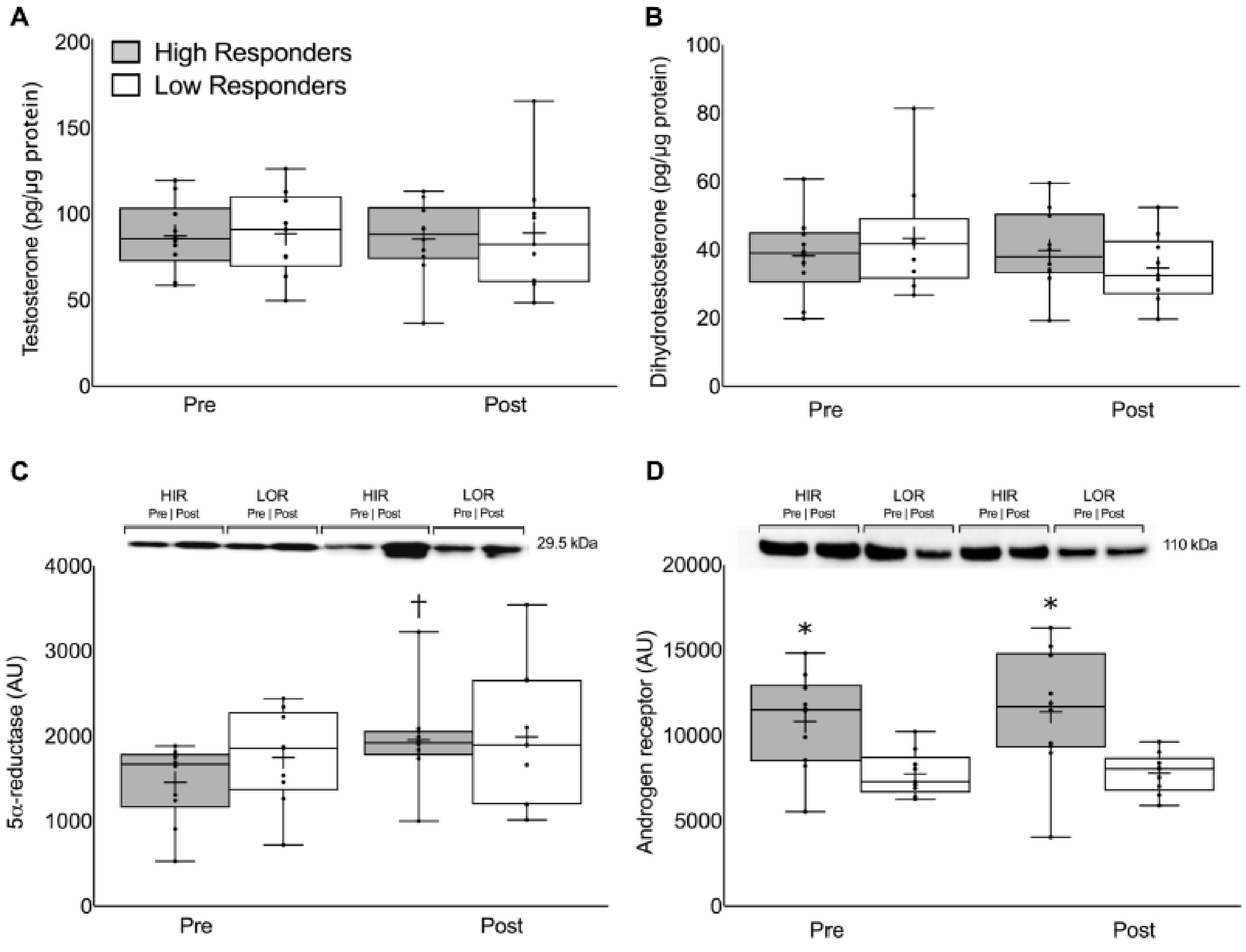
High repetitions: 8-12 reps 75-90%1RM
Low repetitions: 20-25 reps 30-50%1RM

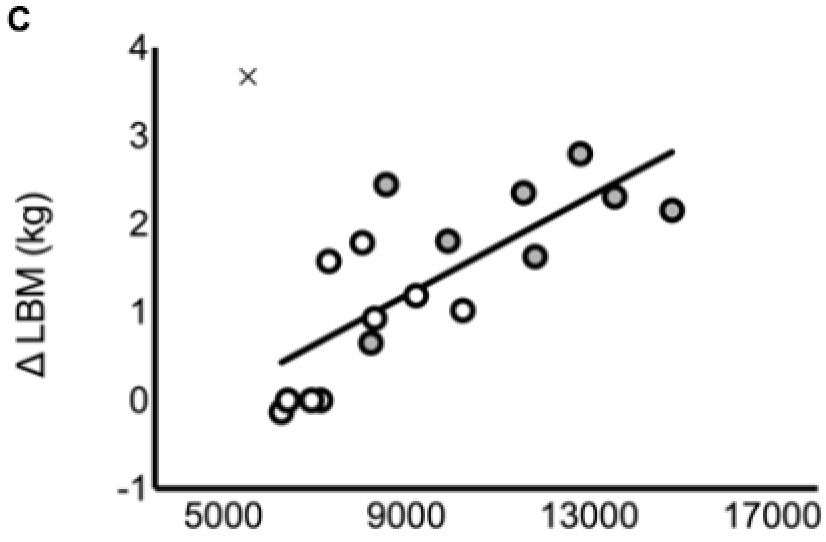
- 49 Resistance trained men (~23y)
- 12 weeks of whole body RE (HR or LR), 4 times/week
- Highest and lowest responders (HIR: n=10, LOR: n=10)
- Received 30 g of protein twice per day



Morton, R. W., Sato, K., Gallaugher, M. P., Oikawa, S. Y., McNicholas, P. D., Fujita, S., & Phillips, S. M. (2018). Muscle androgen receptor content but not systemic hormones is associated with resistance training-induced skeletal muscle hypertrophy in healthy, young men. Frontiers in physiology, 9, 1373.

Androgen receptor is more important than systemic hormones





(r = 0.76, P < 0.01).

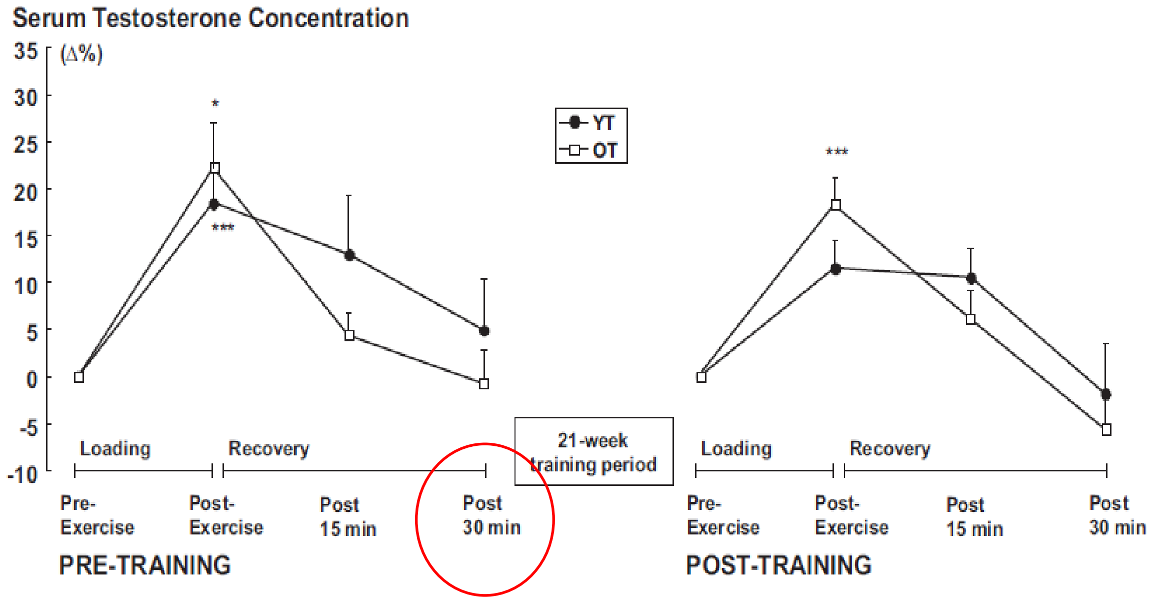
Physiological responses between Young and Old

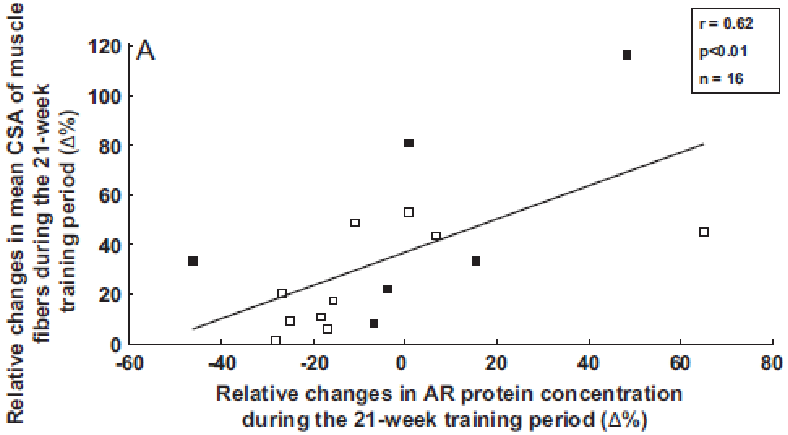
	Younger men		Older men	
	Training group (YT) ($n=7$)	Control group (YC) ($n=10$)	Training group (OT) ($n=10$)	Control group (OC) ($n=8$)
Age (yrs)	28 ± 5	25 ± 3	61 ± 5	64 ± 8
Height (cm)	185 ± 3	185 ± 4	177 ± 3	172 ± 8
Weight (kg)	79 ± 6	76 ± 11	80 ± 5	76 ± 4
Fat %	17 ± 4	16 ± 4	24 ± 3 ## §§§	23 ± 3 ## §§
LBM (kg)	65 ± 4	61 ± 3	61 ± 4	58 ± 10
1 RM (kg)	170 ± 33	161 ± 14	156 ± 24	148 ± 17
BasalT (nmol/l)	17 ± 4	20 ± 6	15 ± 5	18 ± 5

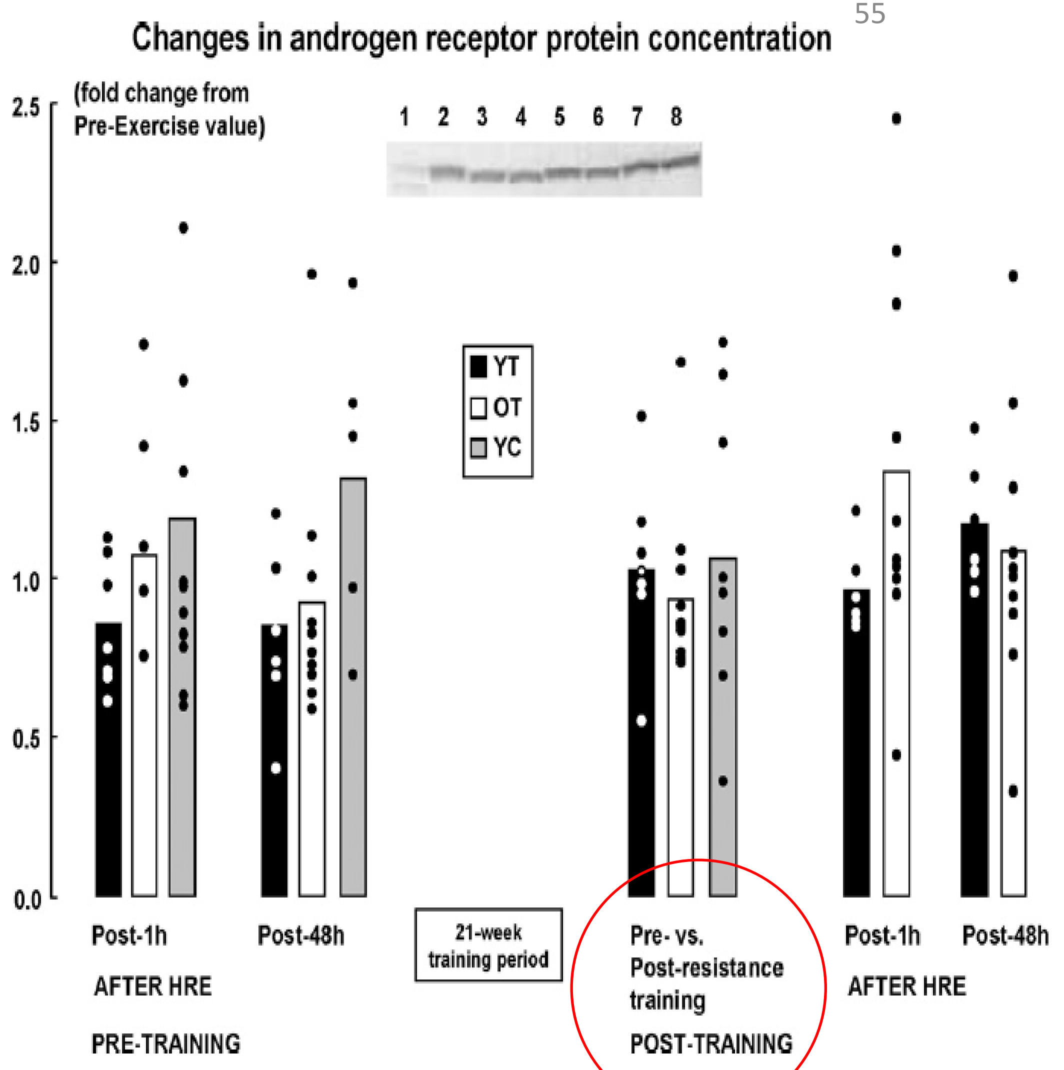
- 21 weeks of RE (2 times/week)
- Leg press and knee extension and flexion exercises were performed for leg muscles. Four to five other exercises were performed for the other main muscle groups of the body (e.g. bench press, triceps pushdown, lateral pull-down, sit-up, elbow flexion).

Ahtiainen, J. P., Hulmi, J. J., Kraemer, W. J., Lehti, M., Nyman, K., Selänne, H., ... & Mero, A. A. (2011). Heavy resistance exercise training and skeletal muscle androgen receptor expression in younger and older men. Steroids, 76(1-2), 183-192.

No significant differences between Young and Old men







Ahtiainen, J. P., Hulmi, J. J., Kraemer, W. J., Lehti, M., Nyman, K., Selänne, H., ... & Mero, A. A. (2011). Heavy resistance exercise training and skeletal muscle androgen receptor expression in younger and older men. Steroids, 76(1-2), 183-192.

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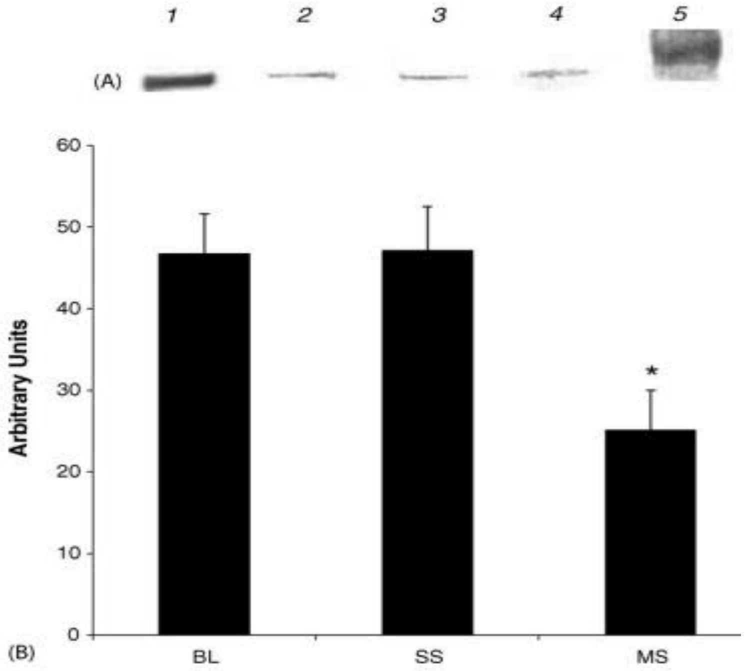
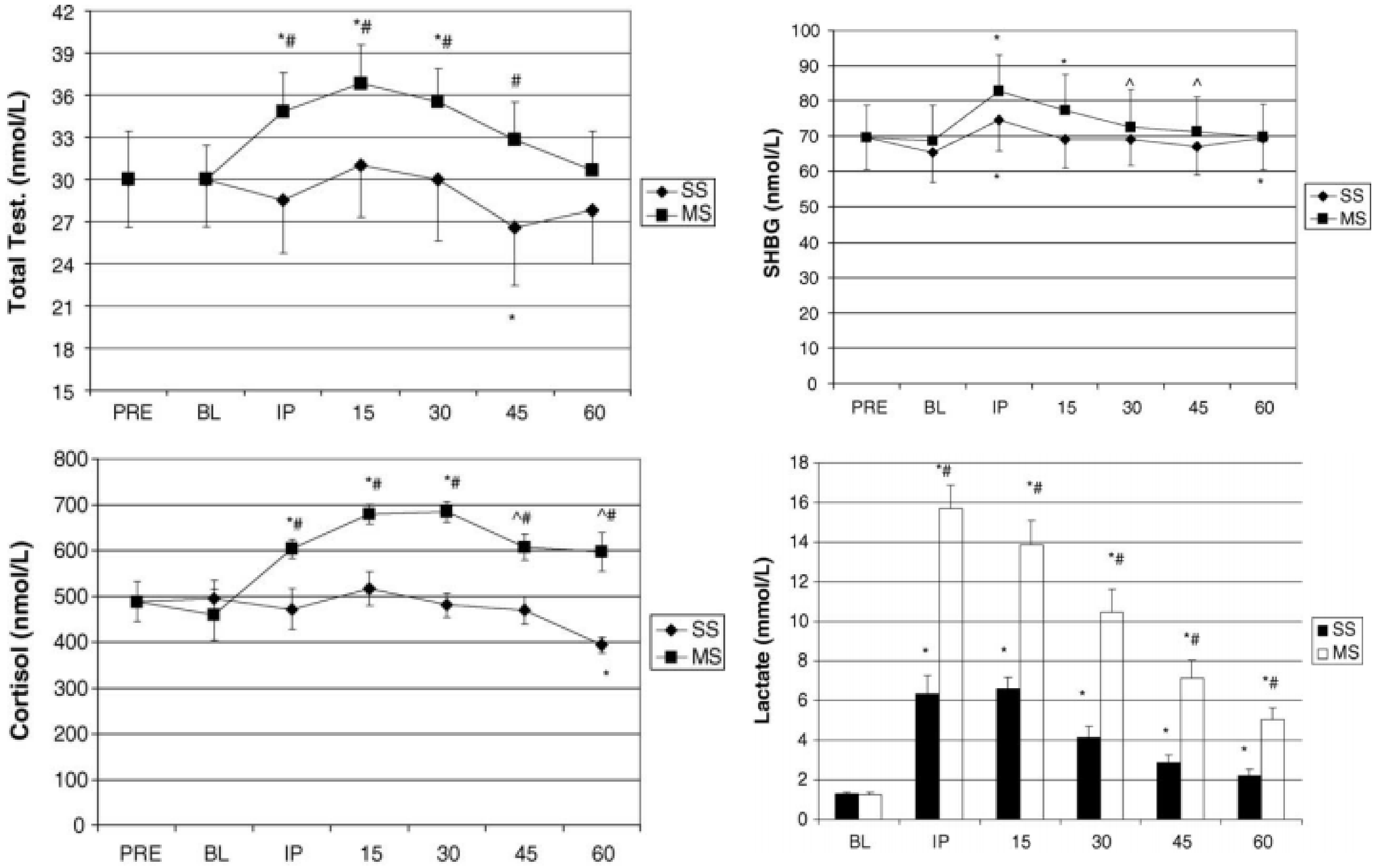
Androgen receptor content reduced after 6 sets of squat in trained men



AUC during 1 h post-exercise



6 vs 1 set of 10RM
Average 1RM = 150kg

Conclusion: greater protein catabolism associated with the higher physiological stress.

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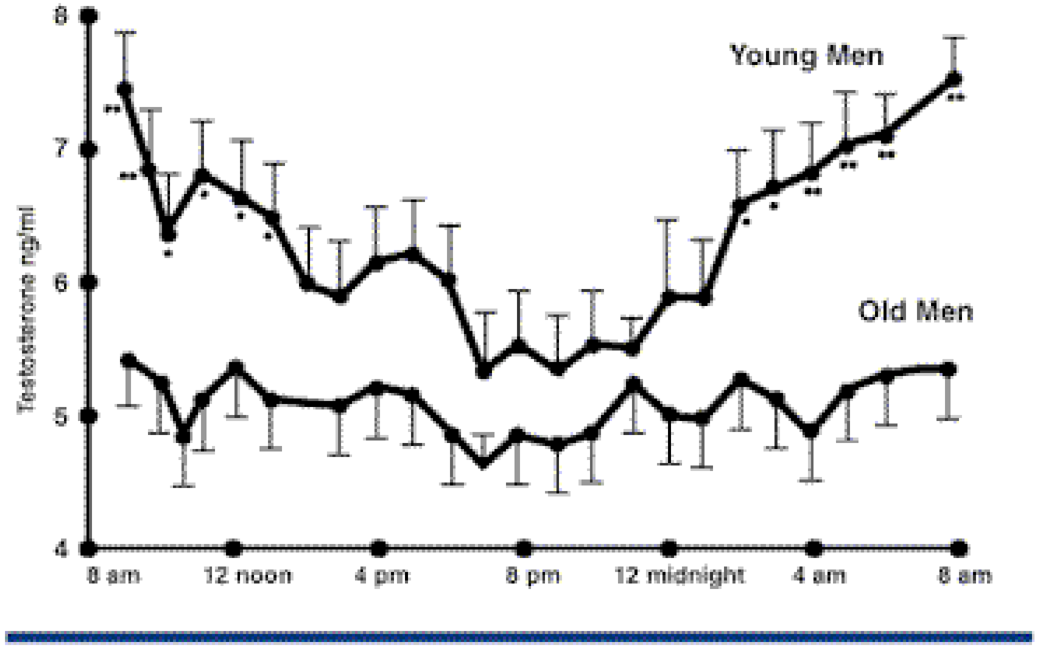
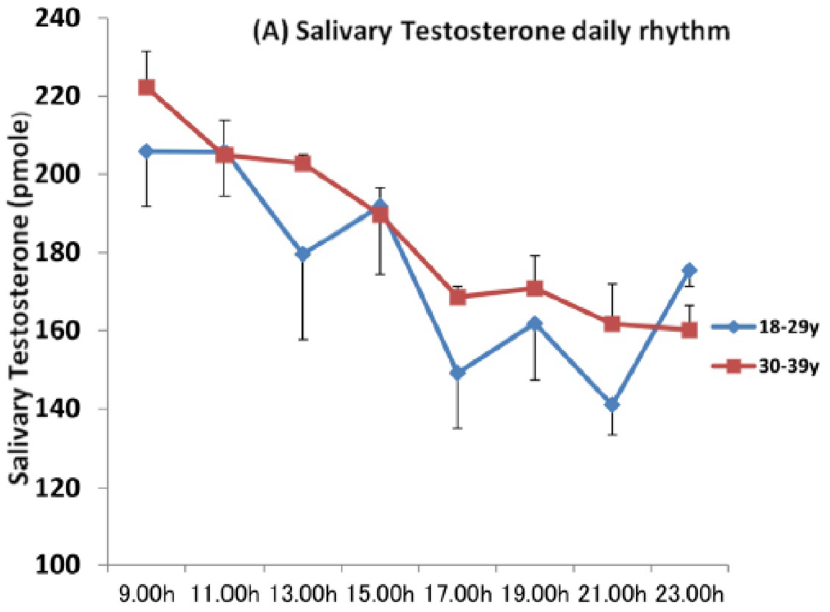
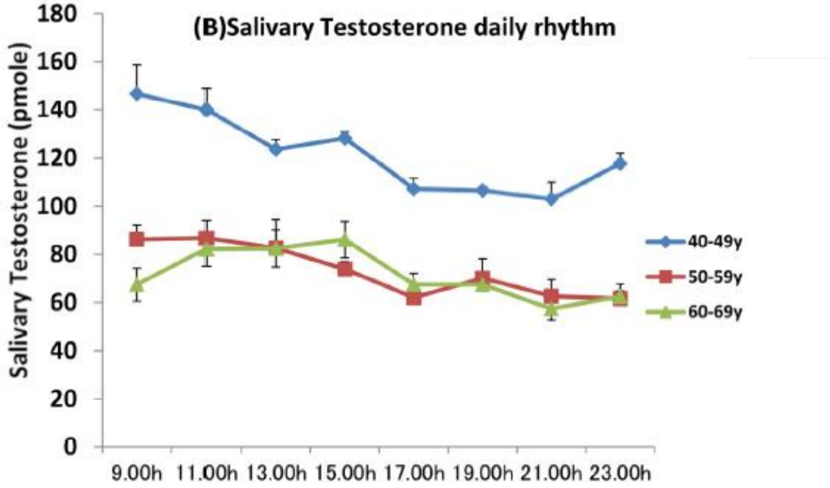
Ratamess, N. A., Kraemer, W. J., Volek, J. S., Maresh, C. M., VanHeest, J. L., Sharman, M. J., ... & Hatfield, D. L. (2005). Androgen receptor content following heavy resistance exercise in men. *The Journal of steroid biochemistry and molecular biology*, *93*(1), 35-42.

Diurnal Rhythm of Testosterone



Bremner, W. J., Vitiello, M. V., & Prinz, P. N. (1983). Loss of circadian rhythmicity in blood testosterone levels with aging in normal men. The Journal of Clinical Endocrinology & Metabolism, 56(6), 1278-1281.





Al-Dujaili, E. A. S., & Sharp, M. A. (2012). Female salivary testosterone: Measurement, challenges and applications. Steroids-From Physiology to Clinical Medicine, 129-167.

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Testosterone replacement therapy (TRT)

來源：成大醫學院附設醫院泌尿部

林宗彥醫師

罩固酮補充治療

- Testosterone levels tend to decrease with age. They peak by early adulthood and then can drop by up to 1% per year beginning around age 40.

Harvard Health Publishing
HARVARD MEDICAL SCHOOL
Trusted advice for a healthier life

睪固酮（Testosterone）是男性相當重要的男性賀爾蒙，它的作用包括促進男性第二性徵表現、調節男性生殖功能、刺激體毛生長以及紅血球製造、維持骨密度、增強肌肉量與強度，改變體脂肪的比率與分部等，缺乏睪固酮時，除了上述功能受到影響，也會影響情緒造成性慾降低、提不起勁、心情鬱悶等情形，當男性體內睪固酮濃度不足的時候，可以在醫師建議下給予適當的睪固酮補充治療。

一、下面四種情形會造成睪固酮濃度不足，可以考慮給予睪固酮補充治療：

1. 雄性激素缺乏症候群(Androgen Deficiency syndrome)：
   雄性激素缺乏症候群顧名思義就是當男性賀爾蒙尤其是睪固酮缺乏時所造成的症狀，如果發生在中老年男性，就是所謂的男性更年期，症狀包括性功能下降、生理體能減退，情緒和認知功能障礙、以及出現心血管疾病等。

2. 男性性功能障礙(sexual dysfunction)：
   這類患者檢查確定睪固酮濃度不足而且合併有缺乏性慾或是勃起功能障礙的情況就可以給予睪固酮補充治療。

3. 年長男性合併以睪固酮濃度不足：
   目前已知隨著年紀越大睪固酮濃度會有下降的情形，但是並不是睪固酮濃度下降就必須給予睪固酮補充治療，一般合併有睪固酮缺乏的症狀或是為了其他治療目的，在醫師跟病人充分解釋且病人了解睪固酮補充治療的好處、副用以及可能的風險後，才建議給予。

4. 慢性疾病合併睪固酮濃度不足：
   目前已知一些慢性疾病像是愛滋病或是長期使用高劑量類固醇的患者會有睪固酮濃度不足的情形，前者給予短期的睪固酮補充治療是為了增加體重以及提高肌肉力量，後者給予睪固酮補充治療是為了幫助病人維持體重以及骨質密度。

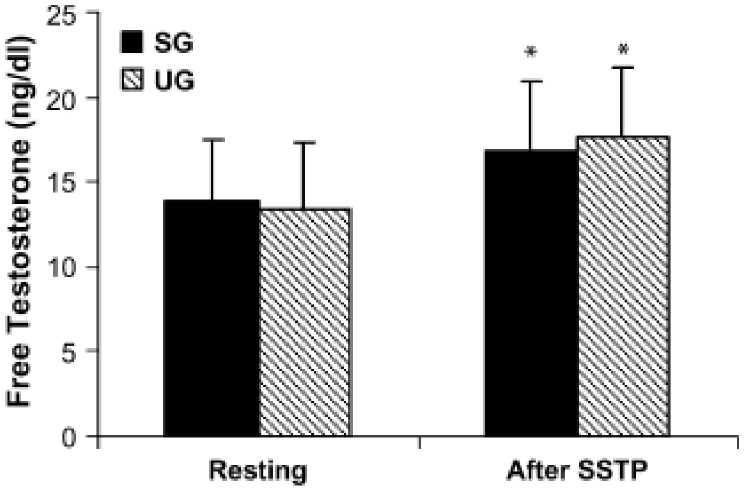
Resistance trained vs untrained middle-age men

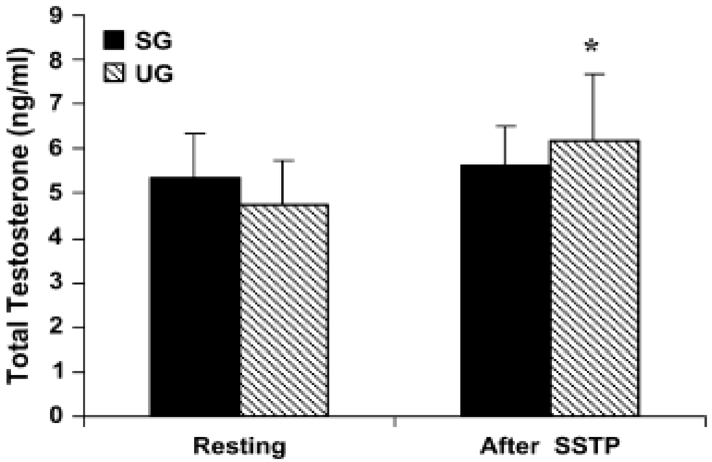
TABLE 2. Training characteristics of the strength-trained group (*n* = 10).

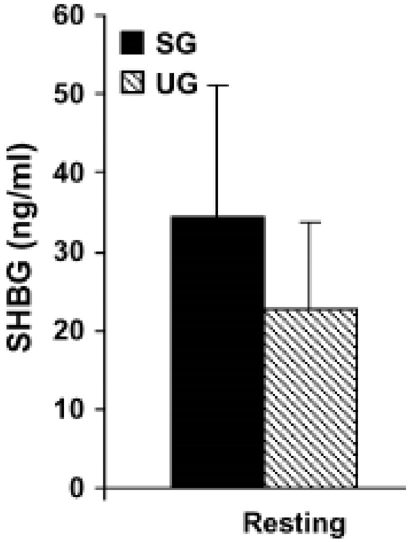
Variable	Mean ± *SD*	Range
Training period (y)	11.77 ± 7	4–25
Sessions per week	5 ± 0.7	4–6
Sets per muscle group	11.1 ± 2	6–16

TABLE 1. Physical characteristics and muscle strength.

	Strength-trained group (*n* = 10)	Untrained group (*n* = 11)
Age (y)	40.5 ± 4.3	40.8 ± 3.8
Height (cm)	175.1 ± 3.9	172.5 ± 7.7
Body mass (kg)	80.4 ± 8.6	79.1 ± 10.02







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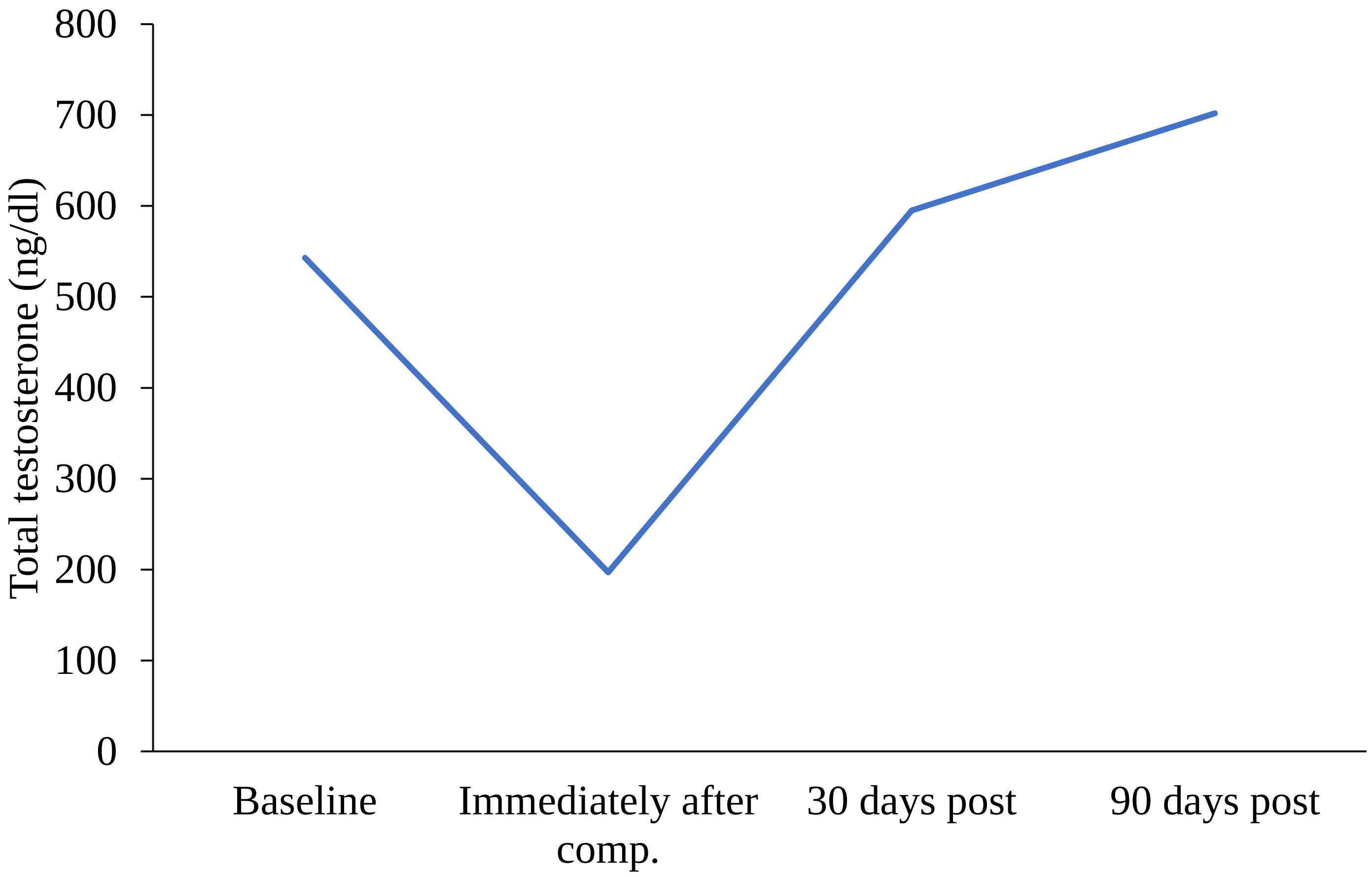
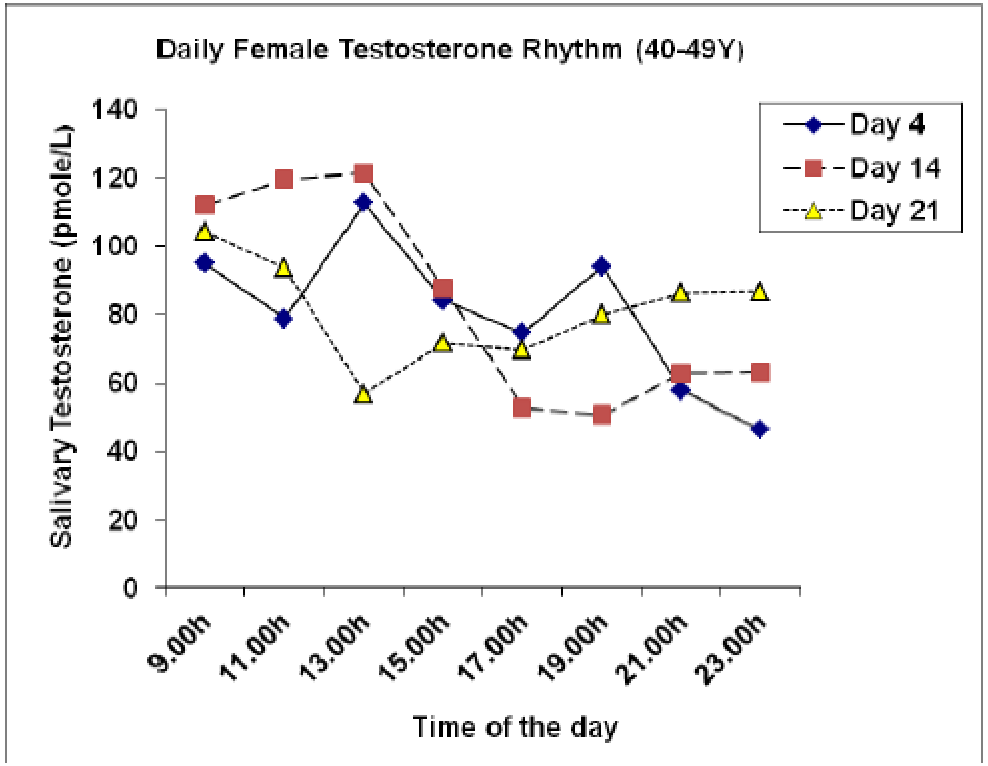
Cadore, E. L., Lhullier, F. L. R., Brentano, M. A., da Silva, E. M., Ambrosini, M. B., Spinelli, R., ... & Kruel, L. F. M. (2008). Hormonal responses to resistance exercise in long-term trained and untrained middle-aged men. *The Journal of Strength & Conditioning Research*, *22*(5), 1617-1624.

Testosterone level before, during, and after competition in a male bodybuilder



Schoenfeld, B. J., Alto, A., Grgic, J., Tinsley, G., Haun, C. T., Campbell, B. I., ... & Trexler, E. T. (2020). Alterations in Body Composition, Resting Metabolic Rate, Muscular Strength, and Eating Behavior in Response to Natural Bodybuilding Competition Preparation: A Case Study. *The Journal of Strength & Conditioning Research*, *34*(11), 3124-3138.

Diurnal Testosterone change during menstrual cycle



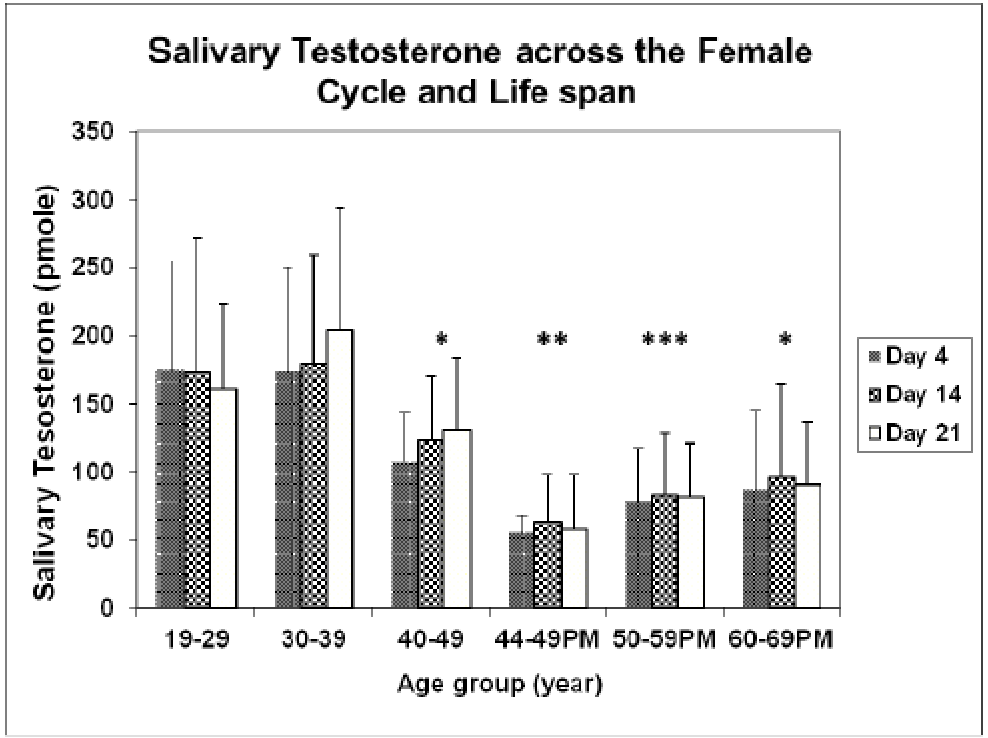
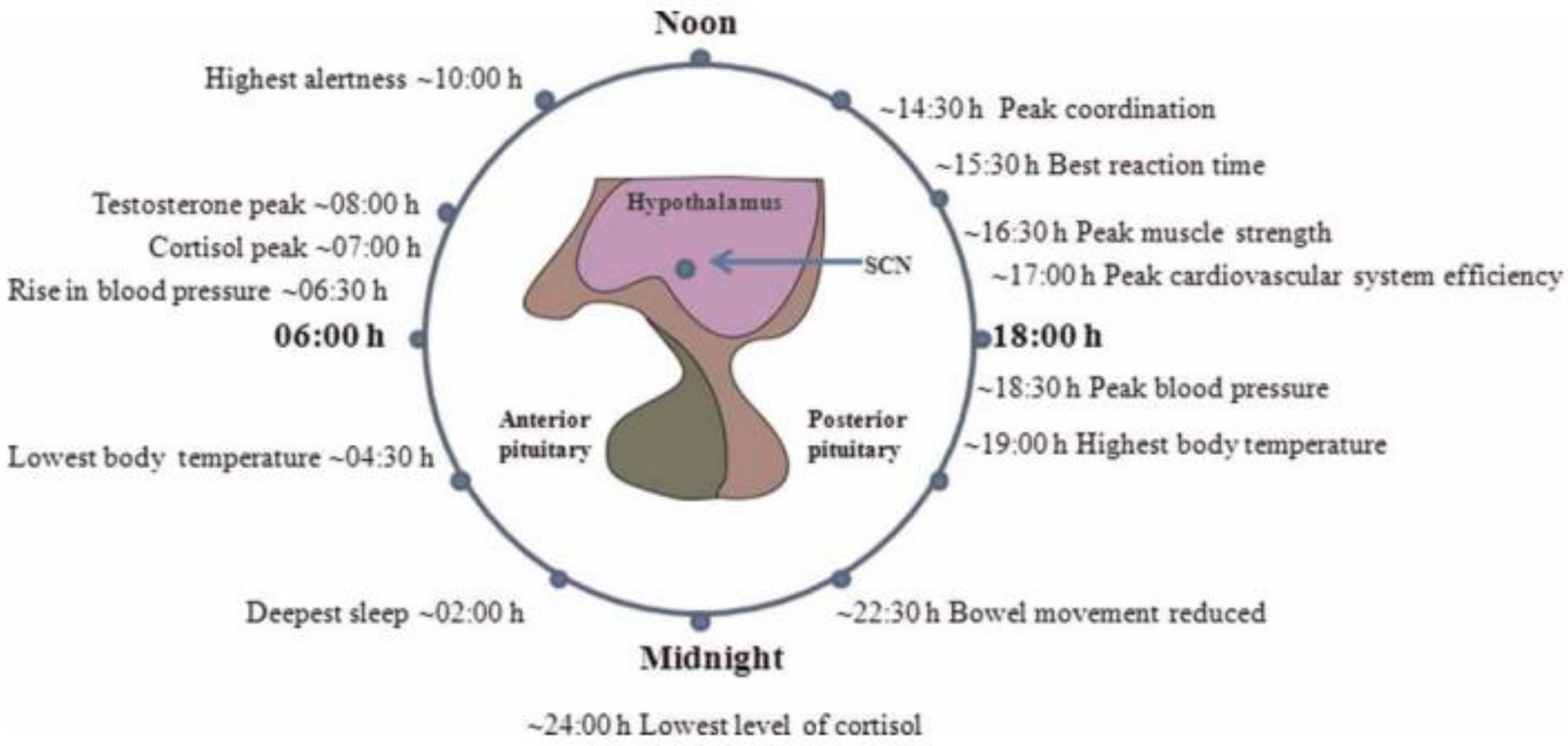


Figure 3. Female salivary testosterone levels in women at 40-49 years showing episodic fluctuations of individual data points exceeding the 09.00 hours levels on some days (Data are mean of 12 females).

Al-Dujaili, E. A. S., & Sharp, M. A. (2012). Female salivary testosterone: Measurement, challenges and applications. Steroids-From Physiology to Clinical Medicine, 129-167.

Circadian rhythms



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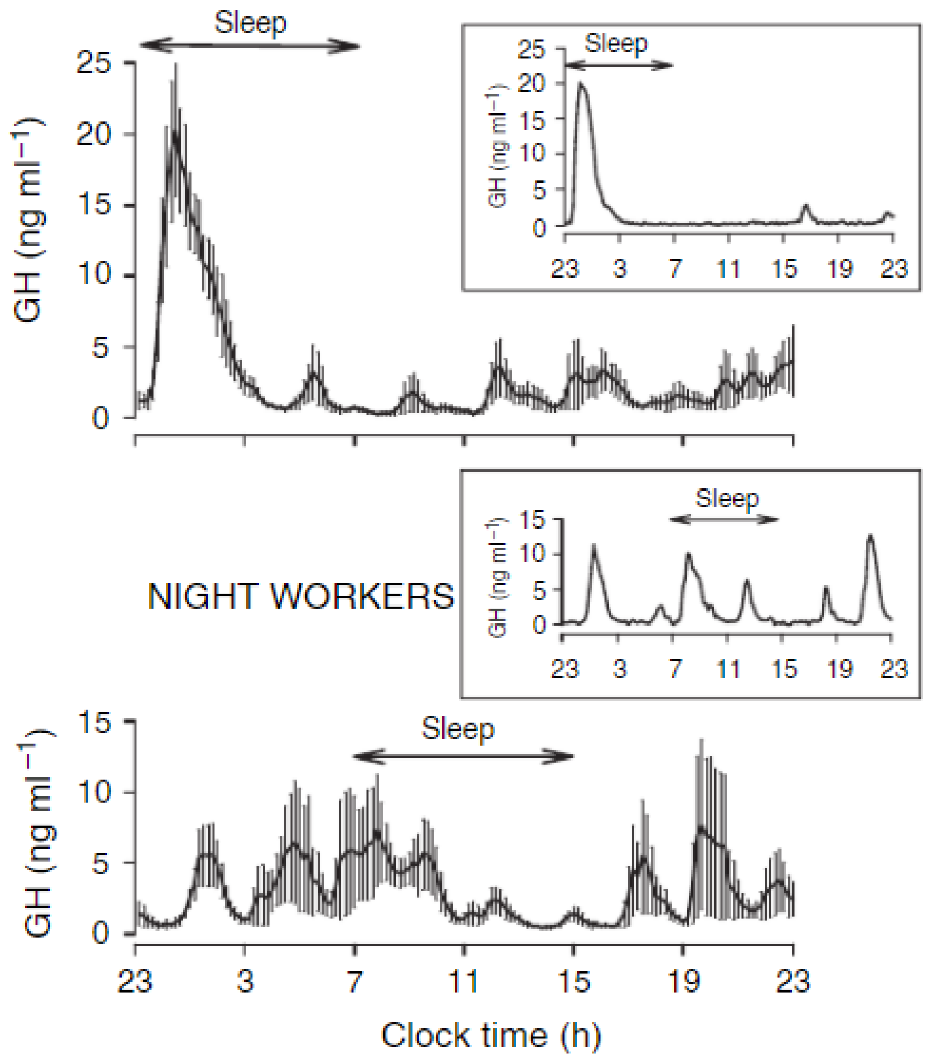
Lawrence D. Hayes, Gordon F. Bickerstaff & Julien S. Baker (2010) INTERACTIONS OF CORTISOL, TESTOSTERONE, AND RESISTANCE TRAINING: INFLUENCE OF CIRCADIAN RHYTHMS, Chronobiology International, 27:4, 675-705, DOI: 10.3109/07420521003778773

Growth hormone

- Growth hormone is a polypeptide hormone considered to have both anabolic and catabolic properties.
- Specifically, GH acts as a repartitioning agent to induce fat metabolism toward mobilization of triglycerides, and stimulating cellular uptake and incorporation of amino acids into various proteins, including muscle.
- 超過100種的型態，最常被研究的是22-kDa isoform
- 運動會誘發GH分泌增加
- It is postulated that a transient GH increase may lead to an enhanced interaction with muscle cell receptors, facilitating fiber recovery and stimulating a hypertrophic response
- Growth hormone is also thought to be involved in the training-induced increase of locally expressed IGF-1.

The 24-h growth hormone rhythm in men



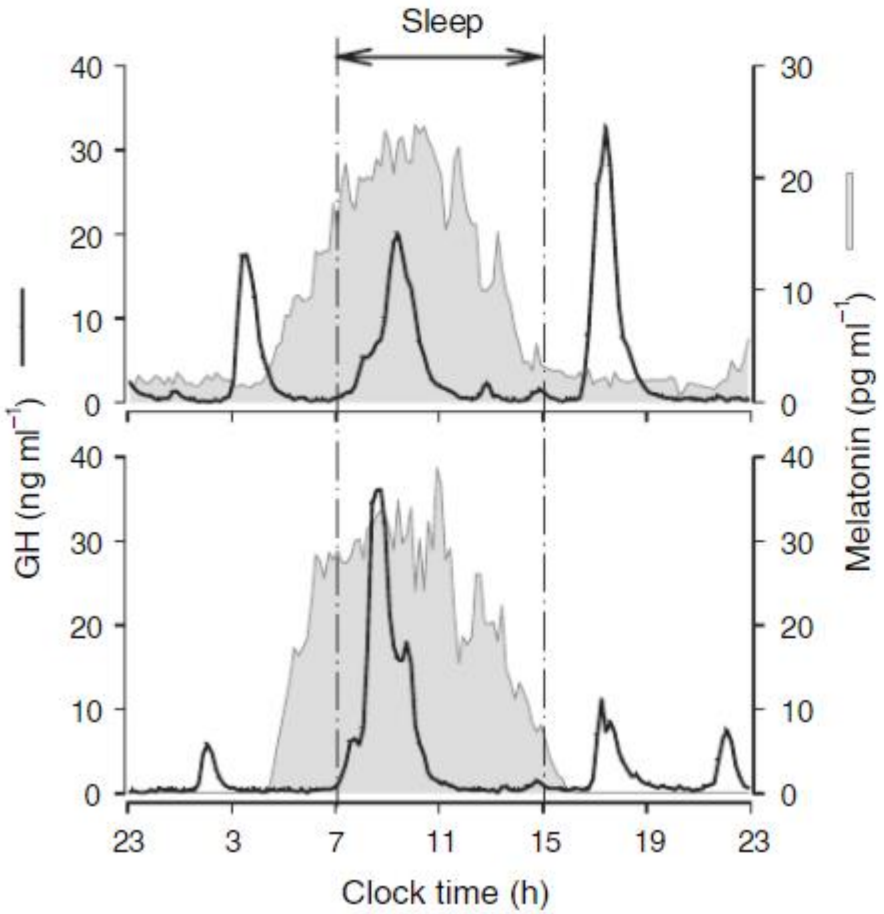


Figure 2. 24-h GH and melatonin profiles in two night workers showing largely differing GH pattern, with a similar shift in their melatonin surge.

Brandenberger, G., & Weibel, L. (2004). The 24-h growth hormone rhythm in men: sleep and circadian influences questioned. Journal of sleep research, 13(3), 251-255.

IGF-1

- The most important mammalian anabolic hormone.
- Three distinct IGF-1 isoforms have been identified: the systemic forms IGF-1Ea and IGF-1Eb, and a splice variant, IGF- 1Ec (受機械信號刺激調控).
- IGF-1 is a peptide hormone, so named because of its structural similarities to insulin.
- Availability of IGF-1 for muscle is controlled by IGF-1 binding proteins (IGFBPs).
- Insulin like growth factor receptors are found in activated satellite cells, adult myofibers, and Schwann cells.
- Insulin-like growth factor has been shown to induce hypertrophy in both an autocrine and paracrine manner and exerts its effects in multiple ways. (蛋白質合成率、調控衛星細胞活化增生分化、活化鈣離子通道基因表現等)

Cortisol–壓力荷爾蒙

Hypothalamic-pituitary-adrenal (HPA) axis

下視丘、腦下垂體、腎上腺軸

Corticotropin-releasing hormone (CRH)

Arginine vasopressin (AVP)

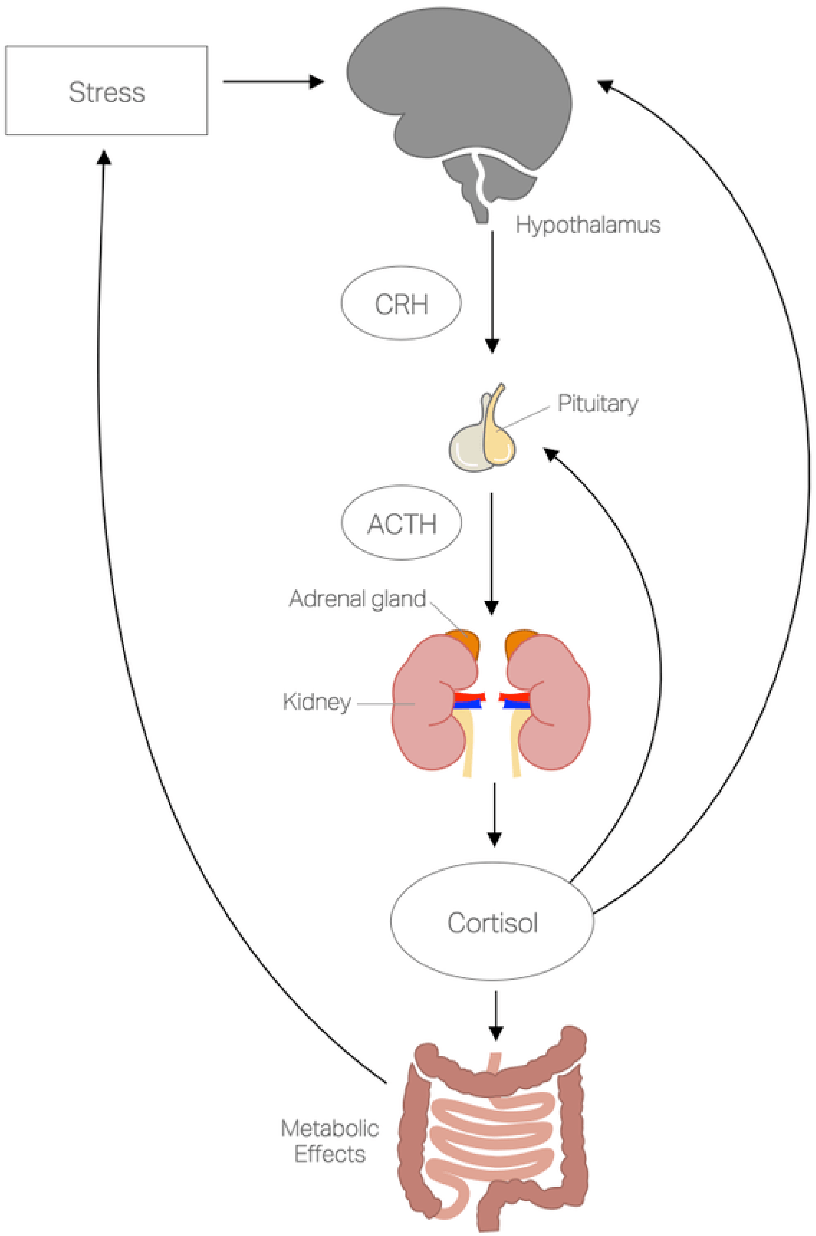
=

Antidiuretic hormone (ADH)

Adrenocorticotropic hormone (ACTH)

糖皮質激素（Glucocorticoid），
主要是皮質醇(Cortisol)

HPA Axis



負回饋機制

Cortisol Awakening Response

- In addition to the diurnal pattern of cortisol secretion, a distinct rise in cortisol has been observed immediately after waking , typically peaking 30–45 min after waking , and has been appropriately termed the **cortisol awakening response (CAR).**

Table 2 CAR as a response to prolonged exercise intervention (n = 13)

Citation	Population	Variable	Exercise intervention	Results
Athletes				
Filaire et al. [45]	12 adolescent female tennis players; 14.8 ±0.6 years	Saliva; 0 h, + 0.5 h; CAR, AUC_g	16 weeks, tennis training program	↓CAR, ↓AUC_g
Gouarne et al. [42]	9 untrained males (25.1 ± 1.4 years), 10 male triathletes (26.5 ± 2.7 years)	Saliva; 0 h, + 0.5 h; $CAR_{\%}$	10 months, triathlon training	↑$CAR_{\%}$ in OT athlete
Gunnarsson et al. [41]	12 crew members of Volvo Ocean Race; 32 years	Saliva; 0 h, + 0.3 h, + 0.6 h; CAR	9 months, round-the-world sailing competition	↓CAR
Minetto et al. [40]	15 male soccer players; 24.4 ± 3.9 years	Saliva; 0 h, + 0.25 h, + 0.5 h; AUC_g, slope	7 days intensified soccer training (60% greater than preceeding months)	↑0 h, AUC_g,
Park et al. [43]	25 male trekkers (14–59 years), 21 male Sherpas (16–39 years)	Saliva; 0 h, + 0.5 h, + 1 h; CAR, AUC_g	Trek to 4800 m	↑CAR, AUC_g@4800 m in trekkers
Military				
Clow et al. [49]	13 male, 7 female military recruits; 17–24 years	Saliva; 0 h, + 0.25 h, + 0.5 h; CAR, AUC_g, MnInc	11 weeks, basic military training	↓AUC_g at week 3 and 6
Non-athletes—yoga				
Curtis et al. [50]	22 female; fibromyalgia; 47.4 ± 13.7 years	Saliva; 0 h, + 0.5 h; CAR	Hatha yoga; 2 × 75-min classes, 8 weeks	No change
Daubenmier et al. [51]	Female; BMI 25–40 kg m^{-2}, < 300 lbs	Saliva; 0 h, + 0.5 h; CAR, slope	9 × 2.5 h + one 7-h guided meditation (inc. yoga)	No change
Non-athletes—aerobic exercise				
Calogiuri et al. [56]	7 male, 7 female sedentary-mod. Active; 49 ± 8 years	Saliva; 0 h, + 0.25 h, + 0.5 h; AUC_i, AUC_g	25 min cycling, 20 min resistance; mod-high intensity (RPE), indoor and nature groups	AUC_i: indoor > nature (p = 0.04)
Foley et al. [52]	23 subjects, experiencing major depressive episode or taking antidepressant	Saliva; 0 h, + 0.5 h; CAR	12 weeks, 30–40 min mod. Aerobic exercise	↓CAR @ 6 and 12 weeks
Foss et al. [53]	15 subjects; 45.2 ± 9.6 years; BMI > 35	Saliva; 0 h, + 0.5 h; CAR	22 weeks, 3 days/week, group-based mod.-vig. exercise	No change
Menke et al. [55]	12 males w/burnout; 12 male controls; 45.4 ± 6.2 years	Saliva; 0 h, + 0.17 h, + 0.34 h, + 0.5 h; AUC_g	12 weeks, 2–3 days/week, aerobic exercise@60–75%HR_{max}	No change
Tortosa-Martinez et al. [54]	21 persons diagnosed with amnestic mild cognitive impairment; 75.5 ± 7.23 years	Saliva; 0 h, + 0.5 h; CAR	Group exercise; 3 months, 3 days/wk., 60 min aerobic exercise@60–75%HR_{max}	No change

BMI body mass index, *RPE* rating of perceived exertion, HR_{max} maximum heart rate, *OT* overtrained

Habitual Morning vs Evening training effect

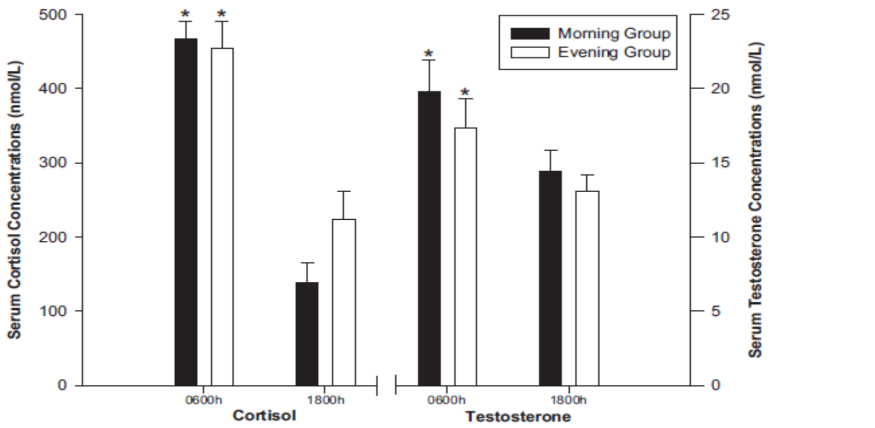
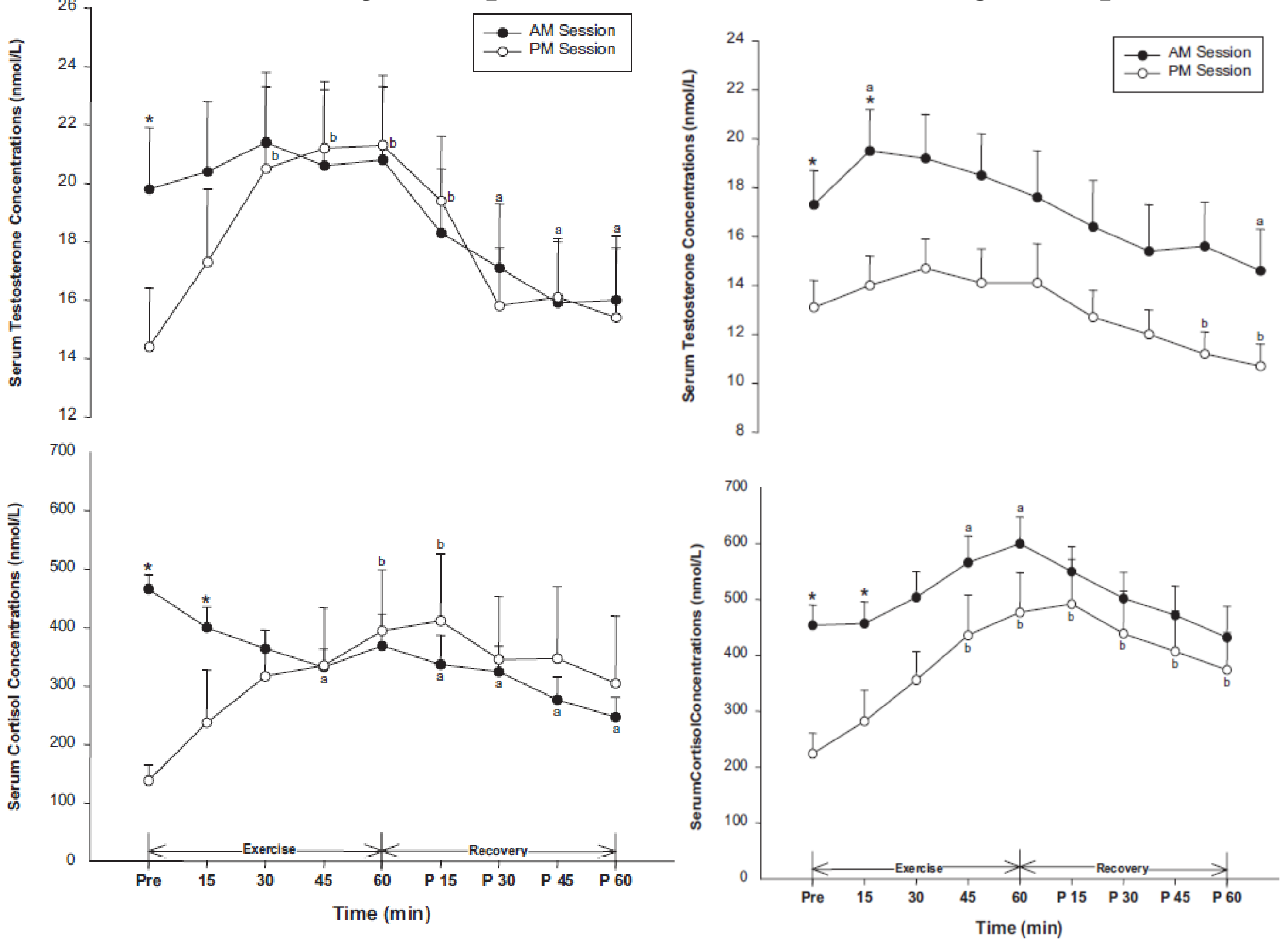


Figure 1. Resting values (means ± SE) in serum cortisol and serum total testosterone.
*Significant difference ($p < 0.05$) from PM (18:00 h) session.

Exercises	Sets	Reps	Equipment
1. Leg press	3	8–10	Panatta sports
2. Leg curl	3	8–10	Panatta sports
3. Leg extension	3	8–10	Panatta sports
4. Shoulder press SM	3	8–10	Panatta sports
5. Lat pulldown	3	8–10	Panatta sports
6. Bench press	3	8–10	York barbell
7. Barbell bicep curl	3	8–10	York barbell
8. Supine tricep extension	3	8–10	York barbell

Morning Group　Evening Group



Bird, S. P., & Tarpenning, K. M. (2004). Influence of circadian time structure on acute hormonal responses to a single bout of heavy-resistance exercise in weight-trained men. *Chronobiology international*, *21*(1), 131-146.

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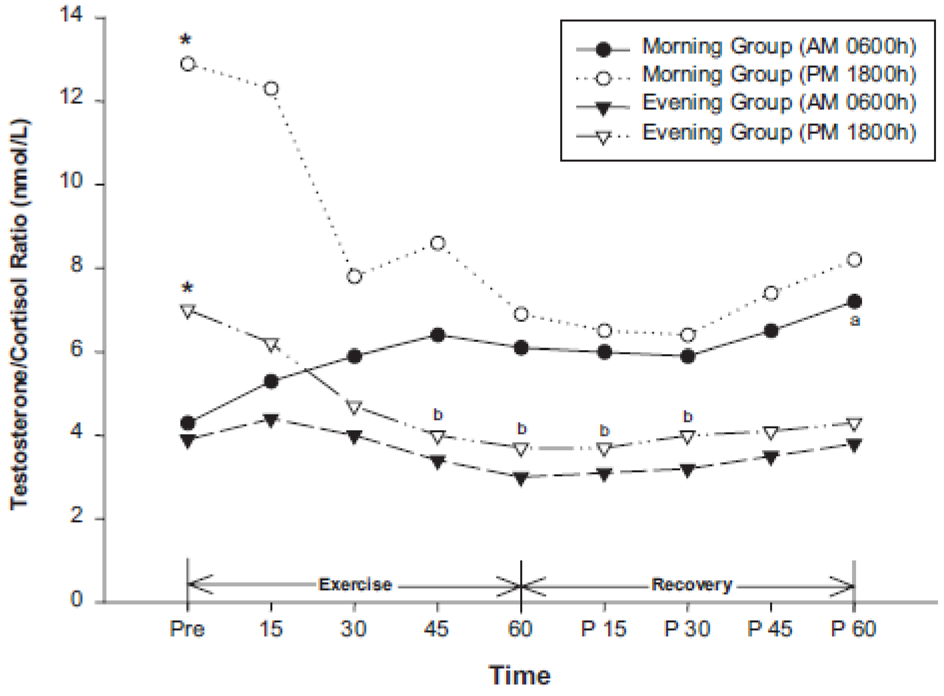
Habitual Morning vs Evening training effect

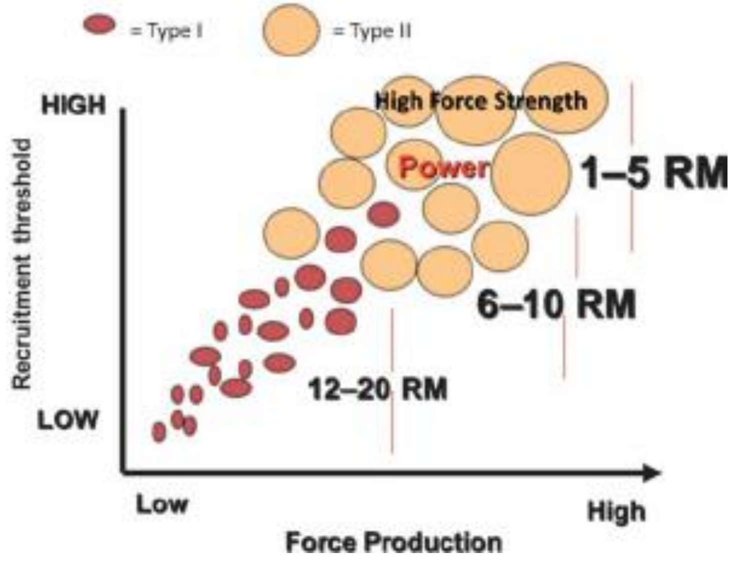
- The findings of the present investigation suggest the optimal time for resistance training is in the evening in order to alter the balance between hormone-mediated anabolic and catabolic activities and enhance anabolic/catabolic status.



荷爾蒙與訓練

急性的荷爾蒙分泌提供資訊給身體

1. 生理壓力（經由腎上腺素）
2. 運動時代謝需求（經由胰島素）
3. 接連改變的休息代謝（受質的利用）



特定的運動模式會有特定的荷爾蒙分泌

1. 高負重→激活高閾值的動作單位
2. 較大力量的輸出→產生之壓力會影響肌漿運輸養分的能力
3. 睪固酮受體的濃度會因為單次的阻力訓練而增加
4. 肌肉纖維神經元的活化會影響荷爾蒙的親和力(結合受器)

Hormonal action are important both during and after an exercise session to respond to the demands of the exercise stress.

Primary hormones and their respective actions

2020 Science and Development of Muscle Hypertrophy, Second Edition

Insulin-like growth factor-1 (IGF-1)	Primary hypertrophic effects of the systemic isoform appear to be in stimulating differentiation and fusion following myotrauma and thereby facilitating the donation of myonuclei to muscle fibers. Although IGF-1 does directly influence anabolic intracellular signaling, it is not clear whether these effects are synergistic for exercise-induced muscle growth.
Growth hormone (GH)	Anabolic effects of GH on muscle tissue are carried out primarily via its potentiating effect on IGF-1. Although some evidence supports that GH promotes anabolism independent of IGH-1, it remains questionable whether these effects have an appreciable impact on postnatal muscle development.
Testosterone	Directly increases myofibrillar protein synthesis and decreases proteolysis. Potentiates the release of GH and IGF-1 while inhibiting activity of IGFBP-4 increases the number of myogenically committed satellite cells.
Insulin	Primary effect on exercise-induced hypertrophic adaptations is believed to be a reduction in protein breakdown as opposed to increases in MPS.

TABLE 1.3 Primary Myokines and Their Respective Actions

Myokine	Actions
Mechano growth factor (MGF)	Believed to kick-start the growth process following resistance training. Upregulates anabolic processes and downregulates catabolic processes. Involved in early-stage satellite cell responses to mechanical stimuli.
Interleukins (ILs)	Numerous ILs are released to control and coordinate the post-exercise immune response. IL-6, the most studied of the ILs, appears to carry out hypertrophic actions by inducing satellite cell proliferation and influencing satellite cell–mediated myonuclear accretion. Emerging research indicates that IL-15 may be important to exercise-induced anabolism, although evidence remains somewhat preliminary. Other ILs also have been postulated to play a role in hypertrophy, including IL-4, IL-7, IL-8, and IL-10, although evidence on their exercise-induced effects remains equivocal.
Myostatin	Serves as a negative regulator of muscle growth. Acts to reduce myofibrillar protein synthesis and may also suppress satellite cell activation.
Hepatocyte growth factor (HGF)	Activated by nitric oxide synthase and possibly calcium–calmodulin as well. HGF is believed to be critical to the activation of quiescent satellite cells.
Leukemia inhibitory factor (LIF)	Upregulated by the calcium flux associated with resistance exercise. Believed to act in a paracrine fashion on adjacent satellite cells to induce their proliferation.

Brad Schoenfeld, PhD

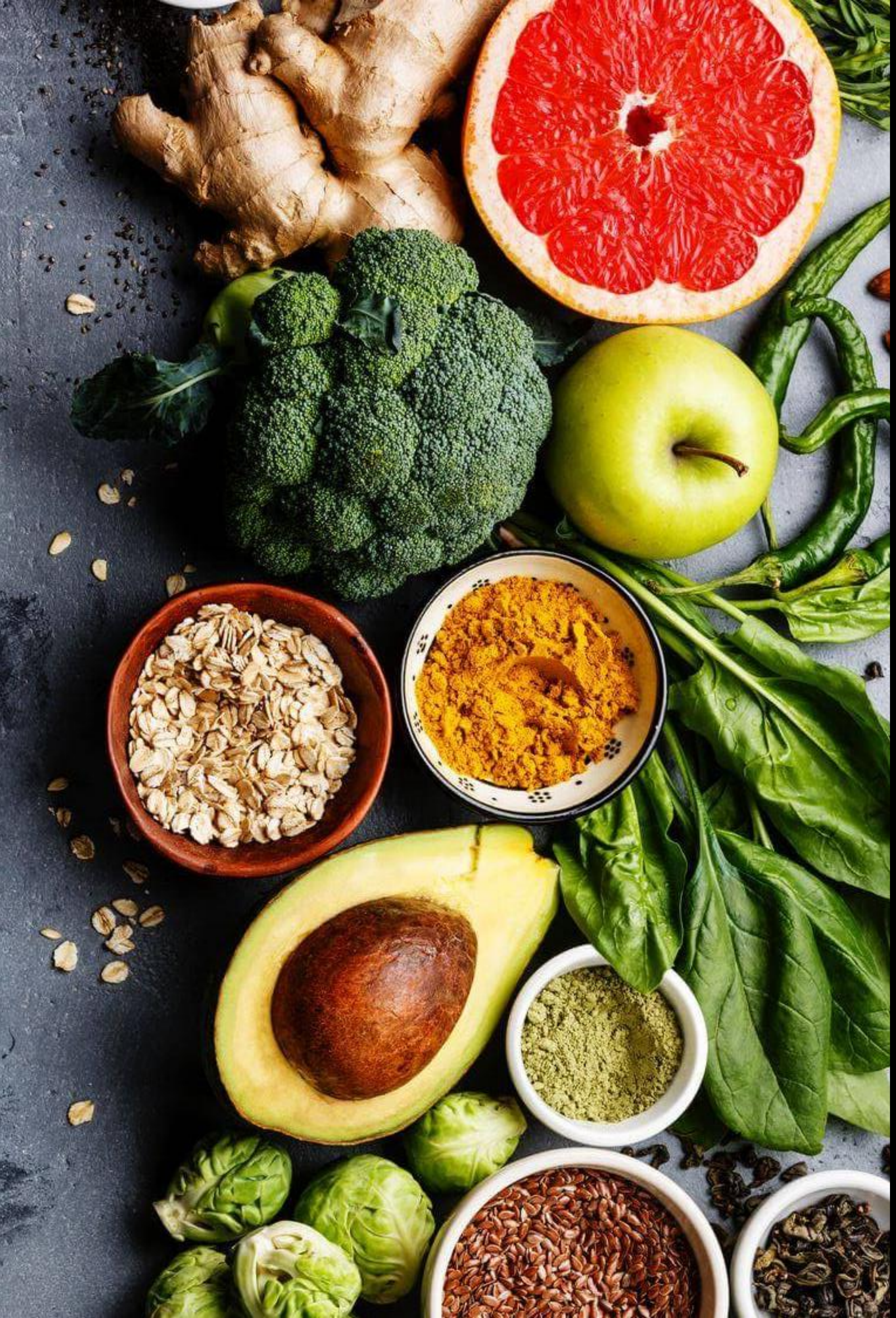
The Mechanisms of Muscle Hypertrophy and Their Application To Resistance Training

- Type of muscle hypertrophy
- Satellite cells and muscle hypertrophy
- Myogenic pathway (Akt/mTOR, MAPK, Calcium dependent pathway)
- Hormone and cytokine (IGF-1, Testosterone, Growth hormone)
- Cell swelling
- Hypoxia
- Initiation of exercise-induced muscle hypertrophy

Schoenfeld, B. J. (2010). The mechanisms of muscle hypertrophy and their application to resistance training. The Journal of Strength & Conditioning Research, 24(10), 2857-2872.

Take home message

- 肌肥大成因、背後機制
- 機械張力、代謝壓力、肌肉損傷
- 體內荷爾蒙、肌肉中的激素會影響身體的變化，但生活中無從得知，故平時需維持良好的作息(晝夜規律)。
- 相較來說，荷爾蒙受器的重要性更高，後天經由訓練改變不大，先天影響很重。
- 每個人需要找到適合自己的訓練模式，而非模仿他人的訓練



Nutritional Periodization: Applications for the Physique Athlete

謝朝傑營養師

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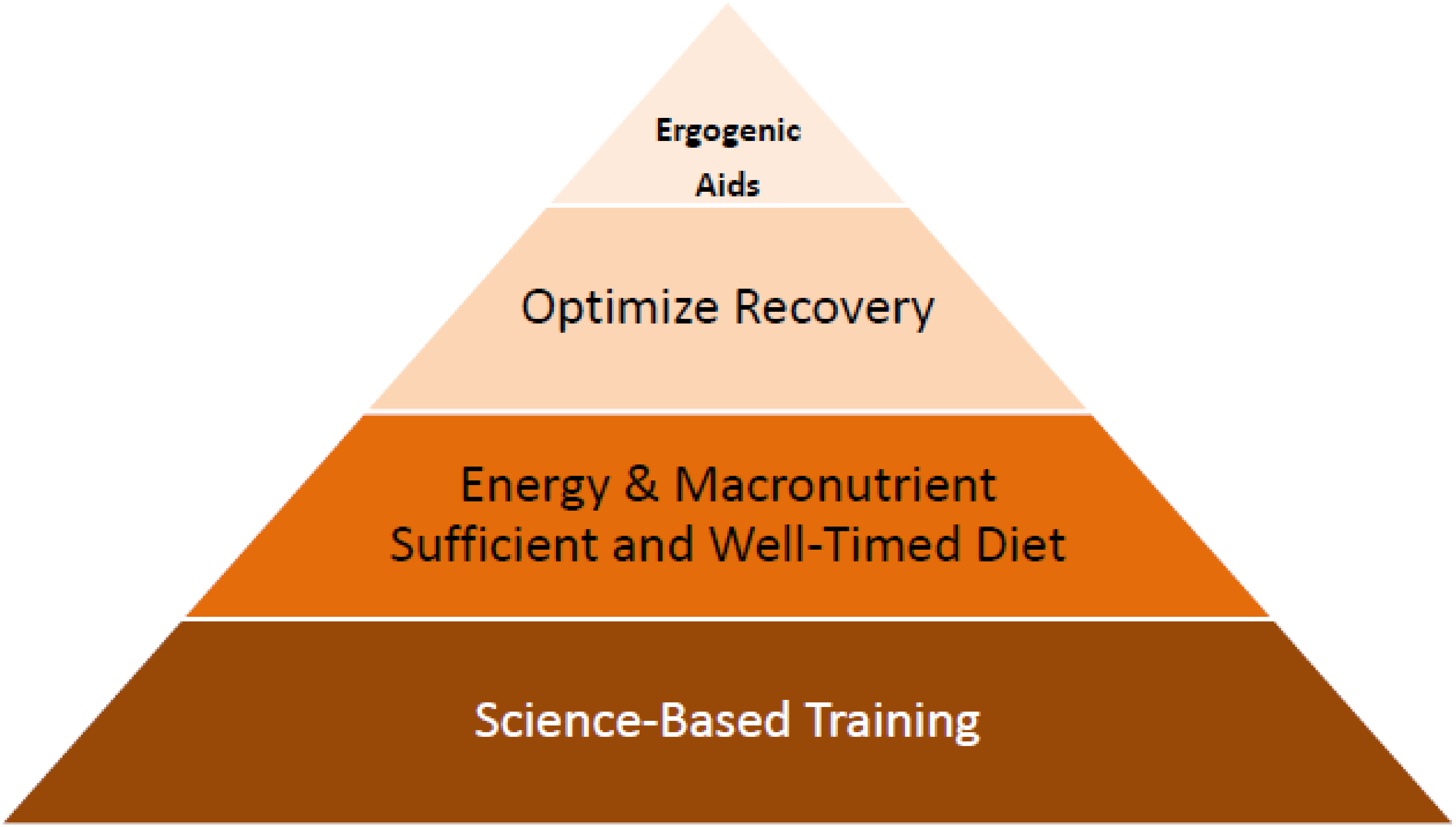
Performance Enhancement Pyramid



Cited: Richard B. Kreider

巨量營養素可接受範圍 AMDR

「國人膳食營養素參考攝取量」第八版

- Acceptable Macronutrient Distribution Ranges

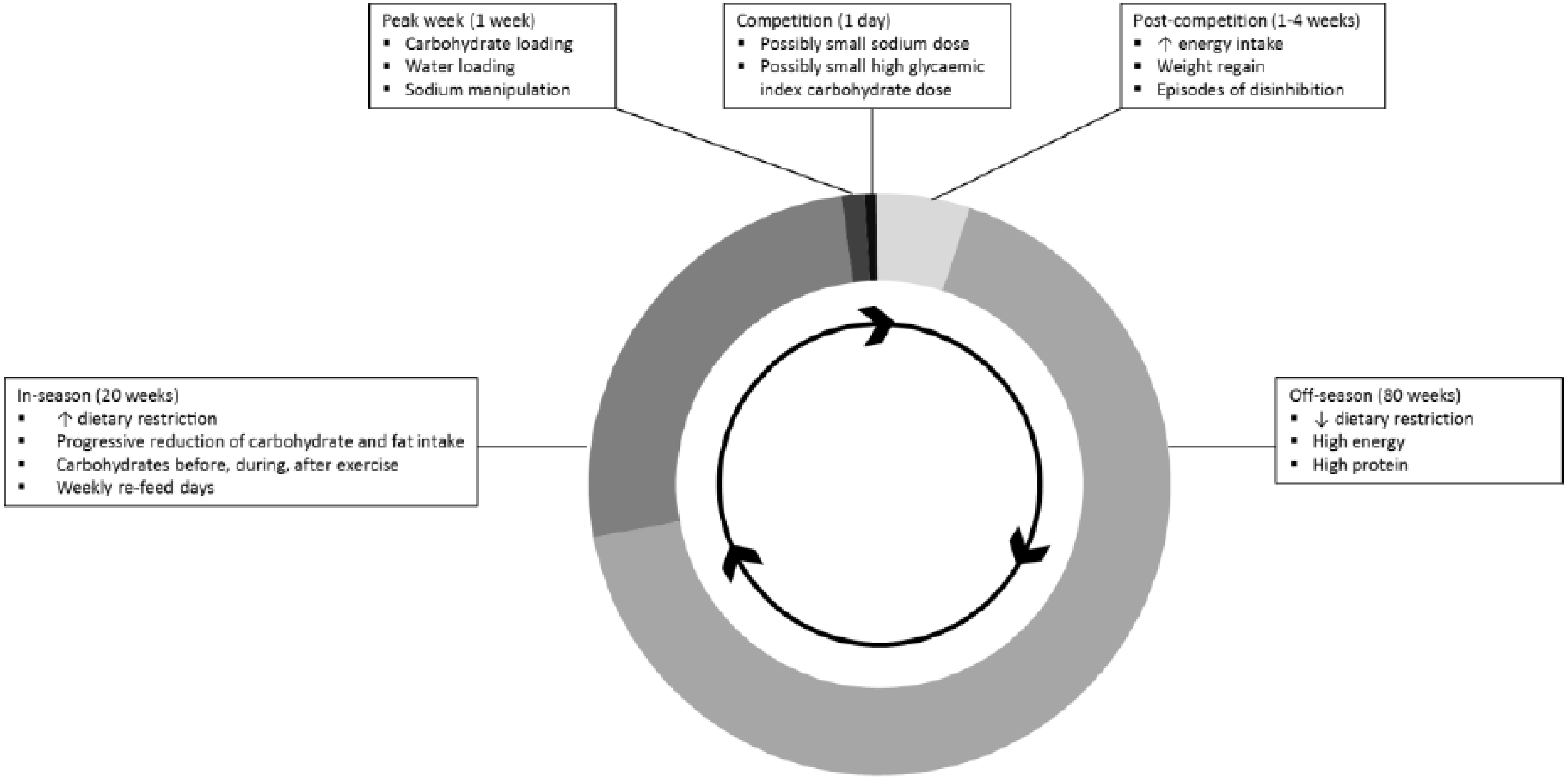
□碳水化合物：50-65%

□蛋白質：10-35%（2002 年美國醫學研究所食品與營養委員會建議 ）

□脂質：20-30%

（飽和脂肪酸：10%以下、n-6多元不飽和脂肪酸4-8%、n-3多元不飽和脂肪酸0.6-1.2%）

Behind the scenes:



Mitchell, L., Hackett, D., Gifford, J., Estermann, F., & O'connor, H. (2017). Do bodybuilders use evidence-based nutrition strategies to manipulate physique?. Sports, 5(4), 76.

年度計畫安排

非賽季力量 → 非賽季增肌 → 賽前減脂 → 比賽周 → 賽後休息

各階段目標				
追求力量表現（神經適應）	追求訓練量（肌肥大）	追求低體脂（熱量赤字）	創造體態（Peak week）	恢復飲食（生理狀態調整）
維持體重	增加體重	減少體重	維持後稍微增加	體重增加

健美選手一年有兩季

Basic Nutrition **for** Strength, Power and Muscle Hypertrophy

- That nutrition plan should meet 3 broad criteria:

(a) Acceptable **caloric intake** to support general health and energetic requirements.

(b) Satisfactory **carbohydrate** consumption to aid in replenishing substrates that were used in high-intensity training.

(c) Adequate **protein** ingestion to maximize muscular adaptations.

Calories

- Maintaining **adequate energy availability** (EA) is necessary to optimize performance, health, and support optimal muscle protein synthesis in all athletes.
- It is estimated that **30–45 kcal · kg of fat-free mass^{-1} · day^{-1}** is necessary to maintain proper metabolic function. (assuming no change in activity level)

70 kg of FFM

2,300 kcal

200 kcal

$$EA = \left[\frac{\text{Energy Intake} - \text{Exercise Energy Expenditure}}{\text{FFM (kg)}}\right]$$

EA =30 kcal · kg FFM^{-1} · day^{-1}

- Caloric intake should reflect energy balance requirements to meet the athlete’s goals for gaining, losing, or the maintenance of body mass.

◻估計能量需求(Estimated Energy Requirements)

成年男性: EER=662-(9.53 x Age) + PA x (15.91 x Weight + 539.6 x Height)

成年女性: EER=354- (6.91 x Age) + PA x (9.36 x Weight + 726 x Height)

		活動層度指數 PAL	活動度 PA
坐姿生活 (Sedentary)	基本的生活活動(家事、走路到車站)	1.0~1.39	1.0
較不活躍 (Low active)	基本的生活活動再加上30-60分鐘的中等層度運動(5-7km/h 的走路)	1.4~1.59	1.11
活躍 (Active)	基本的生活活動再加上60分鐘的中度運動	1.6~1.89	1.25
非常活躍 (Very active)	基本的生活活動再加上至少60分鐘的中度運動和60分鐘的劇烈運動或者120分鐘的中度運動	1.9~2.49	1.48

◻實用運動員熱量計算，特色為可依目標和活動量調整(多少時間內增重或減重) https://bwsimulator.niddk.nih.gov

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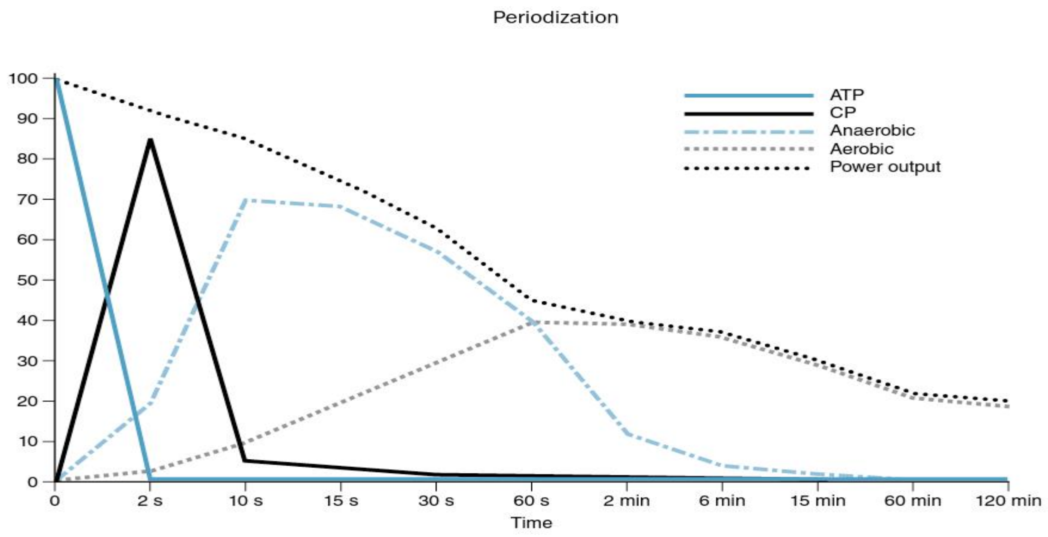
Rodriguez, N. R., Di, N. M., & Langley, S. (2009). American College of Sports Medicine position stand. Nutrition and athletic performance. Medicine and science in sports and exercise, 41(3), 709-731.

Carbohydrate

- **Strength training** may deplete large proportions of muscle **glycogen**, although likely not to the same degree as aerobic exercise.
- The acceptable macronutrient distribution range (AMDR) for carbohydrates is **45–65%** of daily calories.
- As such, to maintain and/or replenish muscle glycogen, 3–5 g of carbohydrate · kg body mass^{-1} may be recommended for strength athletes.



	Anaerobic energy ATP supply predominates			Aerobic energy ATP supply predominates				
	Time (s)			Time (min)				
	10	30	60	2	4	10	30	60
Aerobic ATP supply (%)	3	30	50	60	80	85	95	98
Anaerobic ATP supply (%)	97	73	50	40	20	15	5	2

FIGURE 1.15 Energy provision of the three energy systems.

Adapted from K.A. van Someren, 2006, The physiology of anaerobic endurance training. In *The physiology of training*, edited by G. Whyte (Oxford, UK: Elsevier), 88, and E. Newsholme, A. Leech, and G. Duester, 1994, *Keep on running: The science of training and performance* (West Sussex, UK: Wiley).

Examples of muscle glycogen reduction after RE

1. Roy and Tarnopolsky reported a 36% reduction in vastus lateralis muscle glycogen after 3 rounds of a full-body circuit that contained 3 sets of leg press and 6 sets of leg extension in addition to 6 upper body exercises each with 10 repetitions at 80% 1 RM.

2. Pascoe et al. reported a 29% reduction in glycogen after 6 sets of 6 repetitions of leg extension with 70% 1 RM.

3. Tesch et al. had subjects perform front squats, back squats, leg presses, and knee extensions for 5 sets of 6 to 12 repetitions to muscular failure with a work-to-rest ratio of 1:2 (providing 60~90s rest between sets). Muscle glycogen was reduced ~26%.

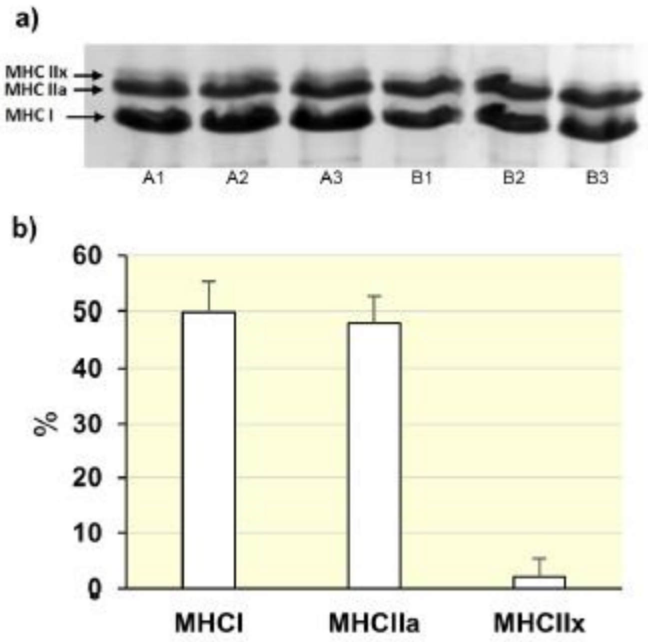
4. Koopman et al. investigated the differences in glycogen depletion between type I and II fibers after 8 sets of 8 repetitions at 75% 1 RM in the leg press and leg extension exercises. An average 33% reduction in muscle glycogen was found, with significant differences between type II fibers (40-44% reduction) and type I fibers (24% reduction).

Carbohydrate Restriction: Friend or Foe

- It appears that low glycogen or carbohydrate availability does not negatively affect acute resistance exercise performance when the volume is less than eight sets) and duration (<45 min) of exercise is low and the intensity is high (>85% 1 RM).
- Increasing carbohydrates after a period of restriction may enhance both acute strength performance (i.e., 1 RM testing during a powerlifting competition) and muscular endurance (i.e., CrossFit).
- Increasing blood glucose before acute resistance exercise via carbohydrate ingestion may result in greater work performed during longer duration (>50 min) resistance training sessions with a higher volume (>10 sets) and moderate intensity (50~75% 1 RM).
- The results from a number of molecular studies reveal that reduced glycogen and blood glucose does not negatively influence the acute MPS stimulating effects of postexercise protein ingestion.
- Although studies with resistance training athletes are limited, it appears that non-severe levels of carbohydrate restriction (i.e., 30~40% total energy) do not negatively influence hypertrophy adaptations, but severe carbohydrate restriction (i.e., <10% total energy, or ketogenic diets) may compromise muscle hypertrophy during a caloric surplus

Cholewa, J. M., Newmire, D. E., & Zanchi, N. E. (2019). Carbohydrate restriction: Friend or foe of resistance-based exercise performance?. Nutrition, 60, 136-146.

一次的重量訓練後，肌肉肝醣減少不多但是....



10 male elite weightlifters performed resistance exercise consisting of 4 sets of 5 (4x5) repetitions at 75% of 1RM back squats, 4x5 at 75% of 1RM deadlifts and 4x12 at 65% of 1RM rear foot elevated split squats.

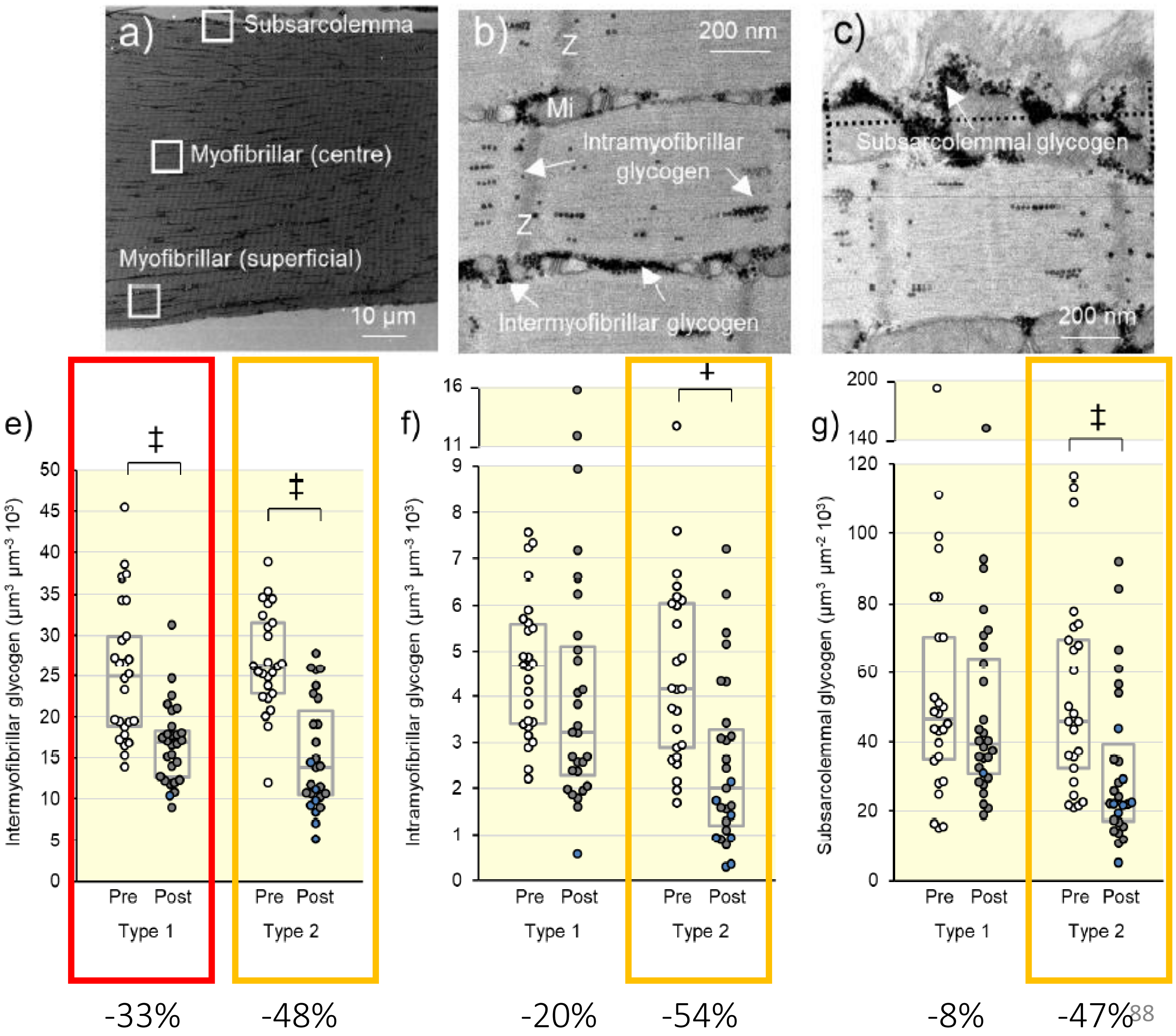
Hokken, R., Laugesen, S., Aagaard, P., Suetta, C., Frandsen, U., Ørtenblad, N., ... & Nielsen, J. (2020). Subcellular localization-and fibre type-dependent utilization of muscle glycogen during heavy resistance exercise in elite power and Olympic weightlifters. *Acta Physiologica*, e13561.

- Total muscle glycogen decreased by about 38%
- 48% of the type 2 fibres demonstrated very low levels of intramyofibrillar glycogen

Table 2. The relative distribution (%) of glycogen at three subcellular locations in human skeletal muscle before and after resistance exercise

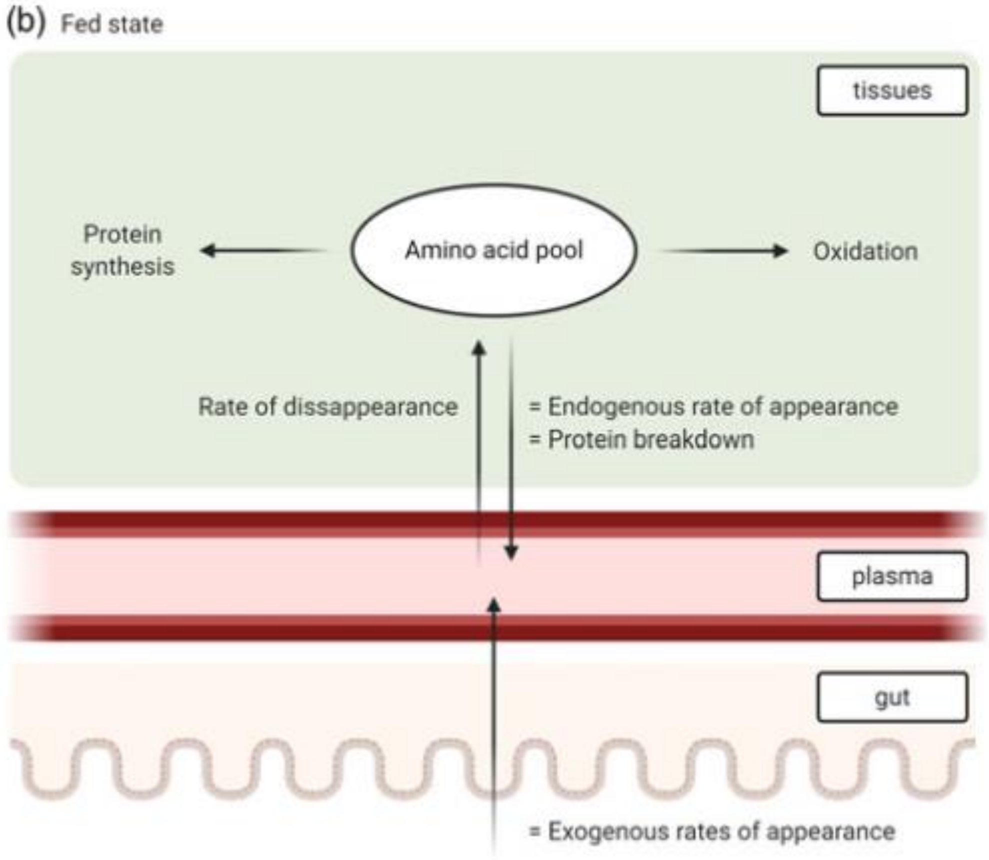
Fibre type	Pre-exercise			Post-exercise		
	IMF	Intra	SS	IMF	Intra	SS
Type 1	81 (78-83)	11 (8-14)	8 (7-10)	76 (72-80)*	12 (9-16)	10 (8-15)
Type 2	82 (77-87)	10 (7-14)	7 (5-9)	83 (78-85)	9 (7-14)	8 (6-12)

IMF, intermyofibrillar glycogen; Intra, intramyofibrillar glycogen; SS, subsarcolemmal glycogen. Values are medians and IQR (n = 24-30 fibres). *, P < 0.05 vs. Pre-exercise



Protein

低脂肪蛋白質食物只能吃乳清和雞胸肉嗎?
蛋白質吃越多越有幫助?



Trommelen, J., & Van Loon, L. (2021). Assessing the whole-body protein synthetic response to feeding in vivo in human subjects. Proceedings of the Nutrition Society, 1-9. doi:10.1017/S0029665120008009

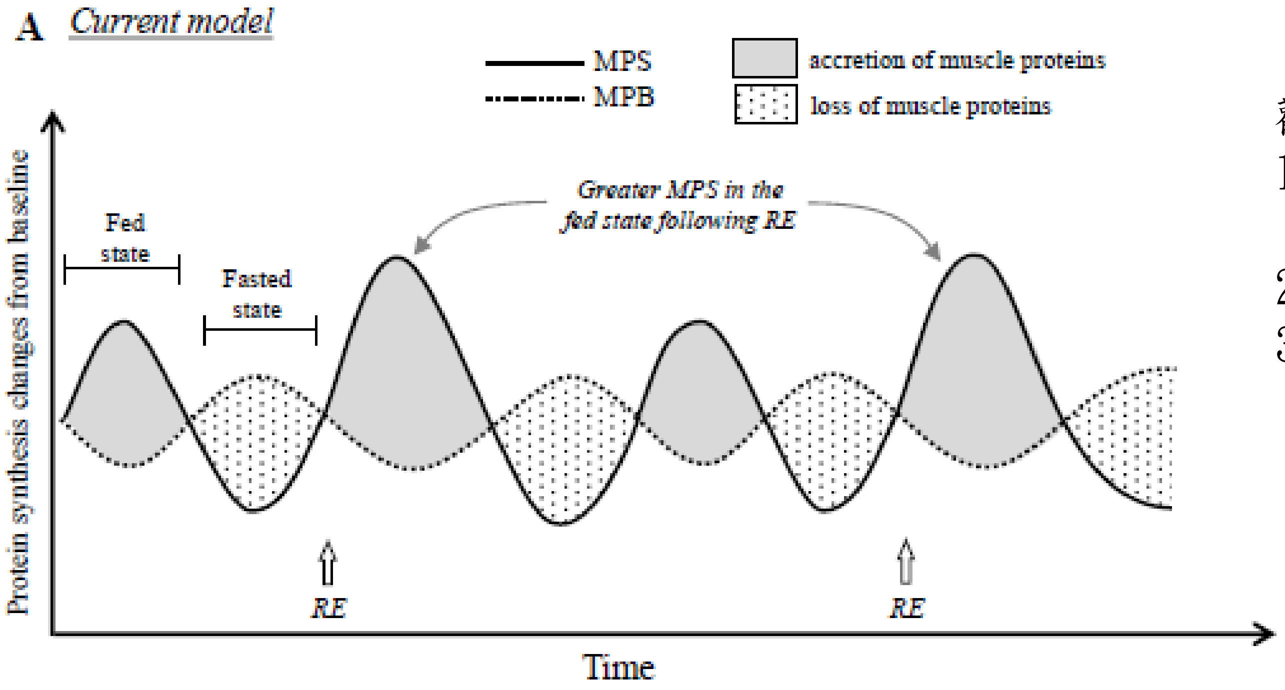
Net Protein Balance

- Positive:

Muscle protein synthesis > Muscle protein breakdown

- Negative:

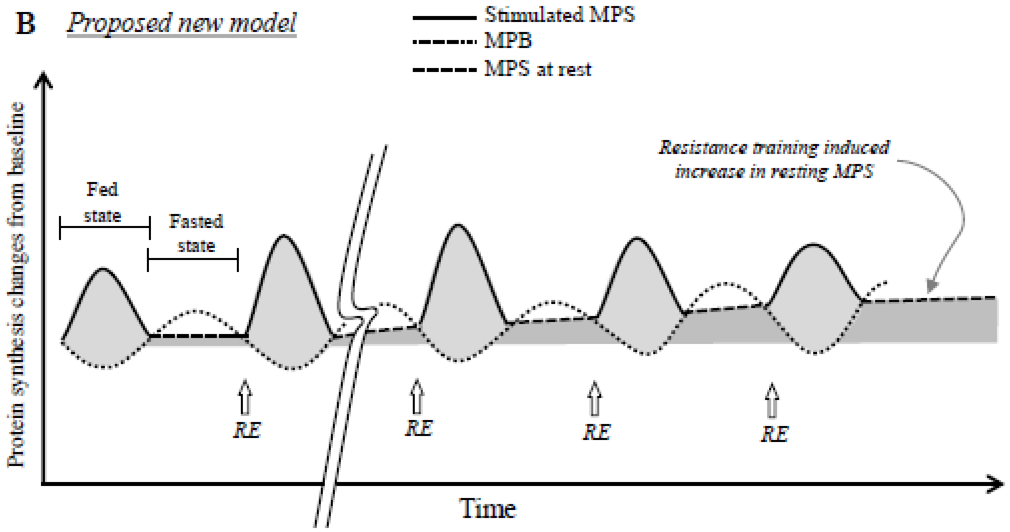
Muscle protein synthesis < Muscle protein breakdown

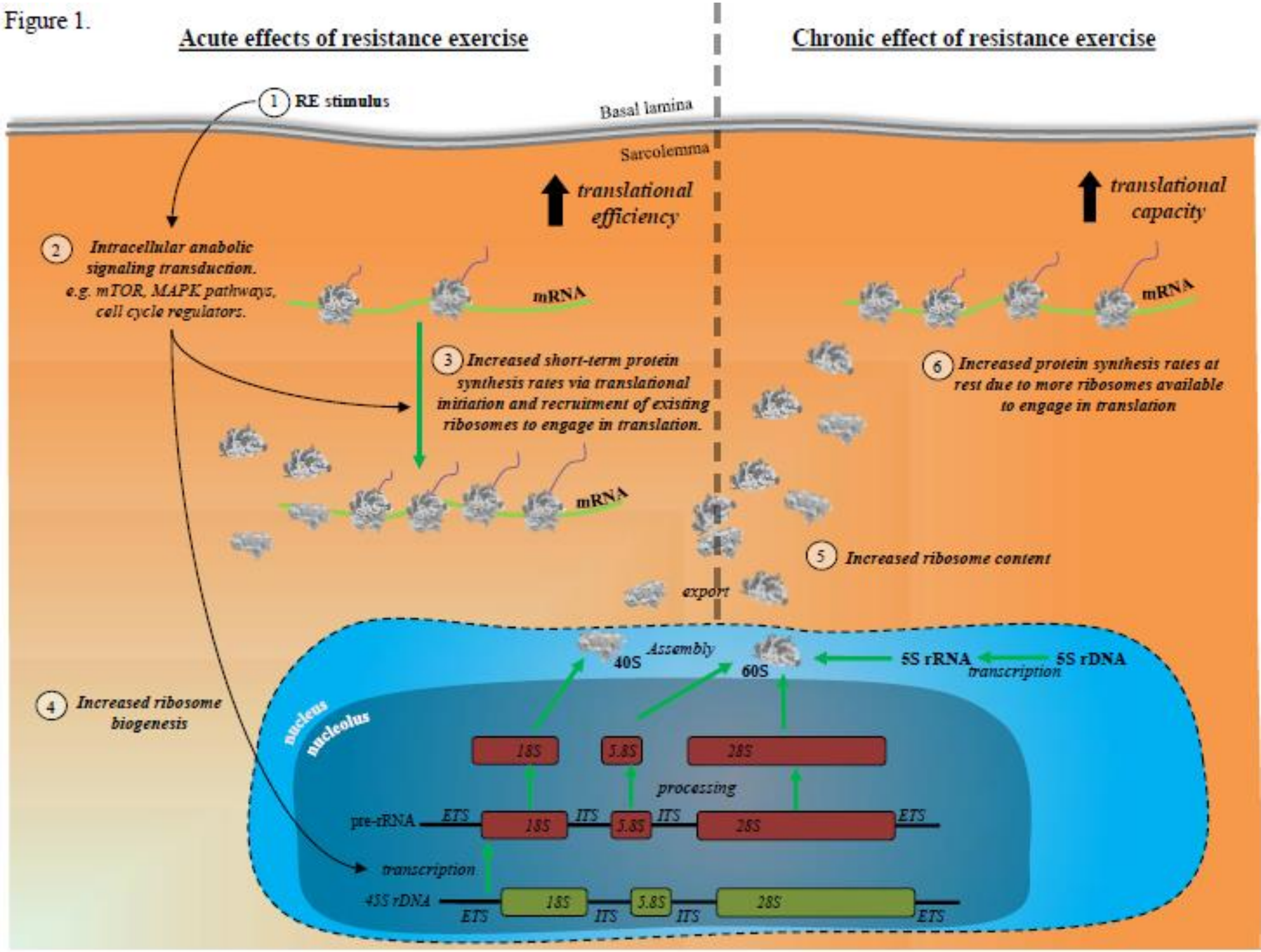


觀念整理：
1. 抑制蛋白質分解→蛋白質或碳水化合物的攝入（胰島素分泌）
2. 運動能刺激蛋白質合成率上升，時間長達72小時
3. 最佳方法：運動訓練並搭配定時的蛋白質攝取

■ 新的假說 – 注重長期效益：

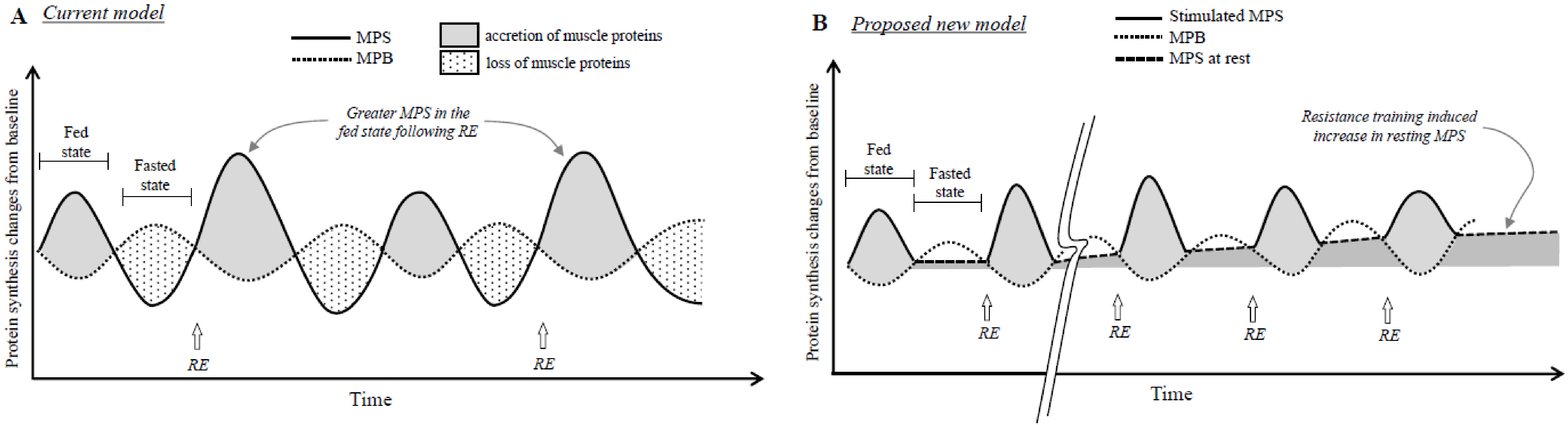
1. 阻力訓練和飲食介入適應後，基礎的合成率增加（轉譯效率提升）
2. 單次阻力訓練造成的“運動後合成率增加量”漸減





Figueiredo, V. C. (2019). Revisiting the roles of protein synthesis during skeletal muscle hypertrophy induced by exercise. American Journal of Physiology-Regulatory, Integrative and Comparative Physiology, 317(5), R709-R718.

Hypothesis of muscle hypertrophy



1. 每次的進食及訓練使得合成率急性增加
2. 每次的正平衡加總後使得肌肉成長
3. 因此在這觀念下運動後的立即進食變得很重要

1. 注重長期的適應結果
2. 每次的訓練和飲食累積下來，使得身體的基礎(休息時)轉譯效率提升，並且”訓練造成的蛋白質合成率增加量”會逐漸減少

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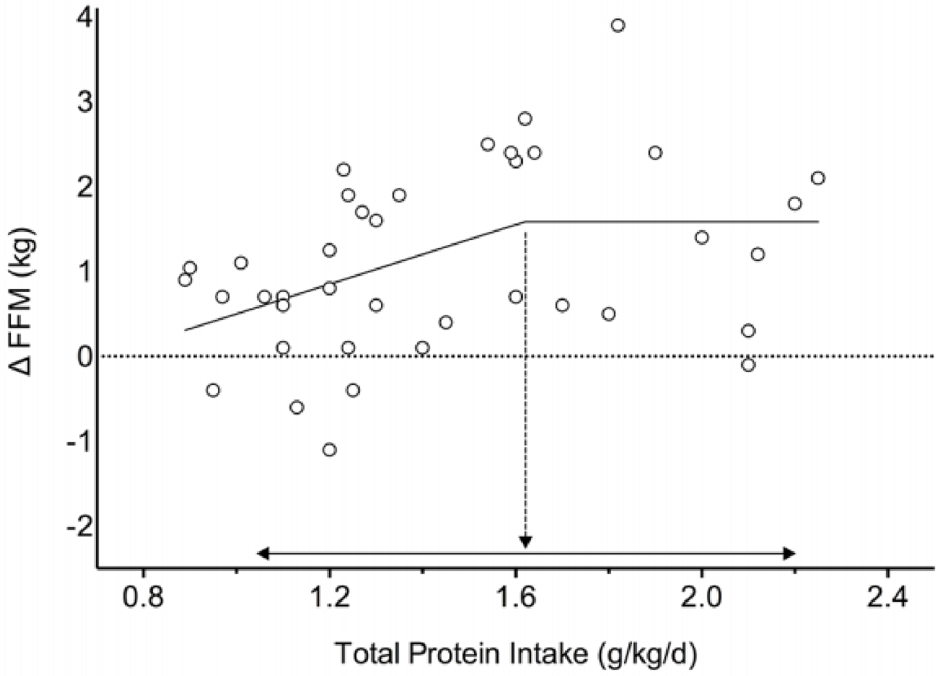
Figueiredo, V. C. (2019). Revisiting the roles of protein synthesis during skeletal muscle hypertrophy induced by exercise. American Journal of Physiology-Regulatory, Integrative and Comparative Physiology, 317(5), R709-R718.

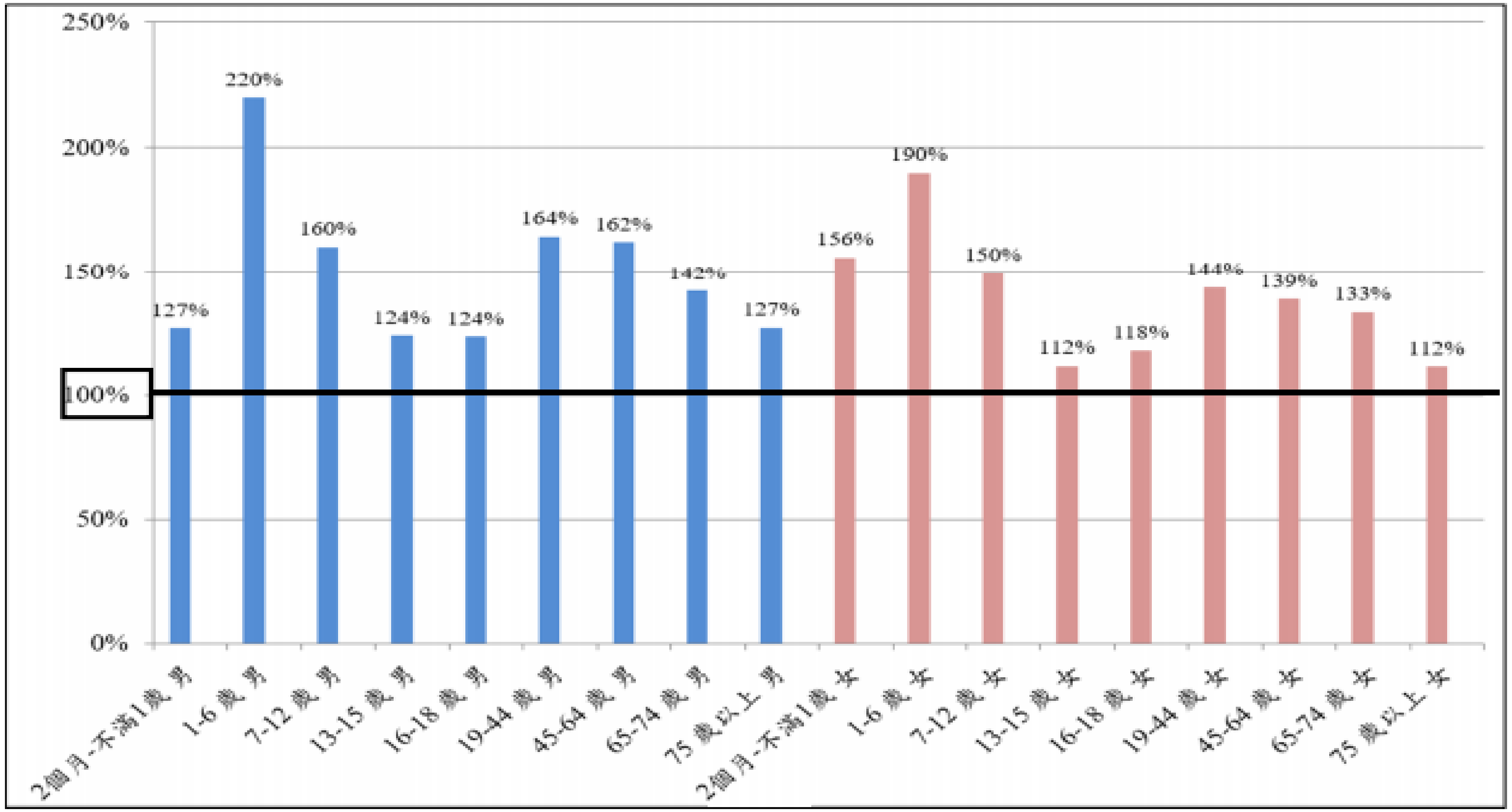
Protein

- Dietary protein supports muscle growth and repair after training, in addition to limiting or attenuating loss of FFM and maintaining satiety when in a hypocaloric state.
- The AMDR for protein intake has been set at 10–35% of total energy.
- The recent literature has reported that 1.6 g of protein · kg body mass^{-1} was necessary to maximize gains in lean body mass (LBM) during resistance training.
- Furthermore, up to 2.4 g of protein · kg body mass^{-1} has been recommended for athletes under hypocaloric conditions.



Morton, R. W., Murphy, K. T., McKellar, S. R., Schoenfeld, B. J., Henselmans, M., Helms, E., ... & Phillips, S. M. (2018). A systematic review, meta-analysis and meta-regression of the effect of protein supplementation on resistance training-induced gains in muscle mass and strength in healthy adults. British journal of sports medicine, 52(6), 376-384.

國人蛋白質攝取已經足夠



第七版國民蛋白質建議攝取量每公斤體重0.9克

圖 3.4.2 民國 102-105 年性別、年齡別之蛋白質攝取狀況

(1)DRIs%：蛋白質攝取量與第七版國人膳食營養素參考攝取量（DRIs）之相比結果

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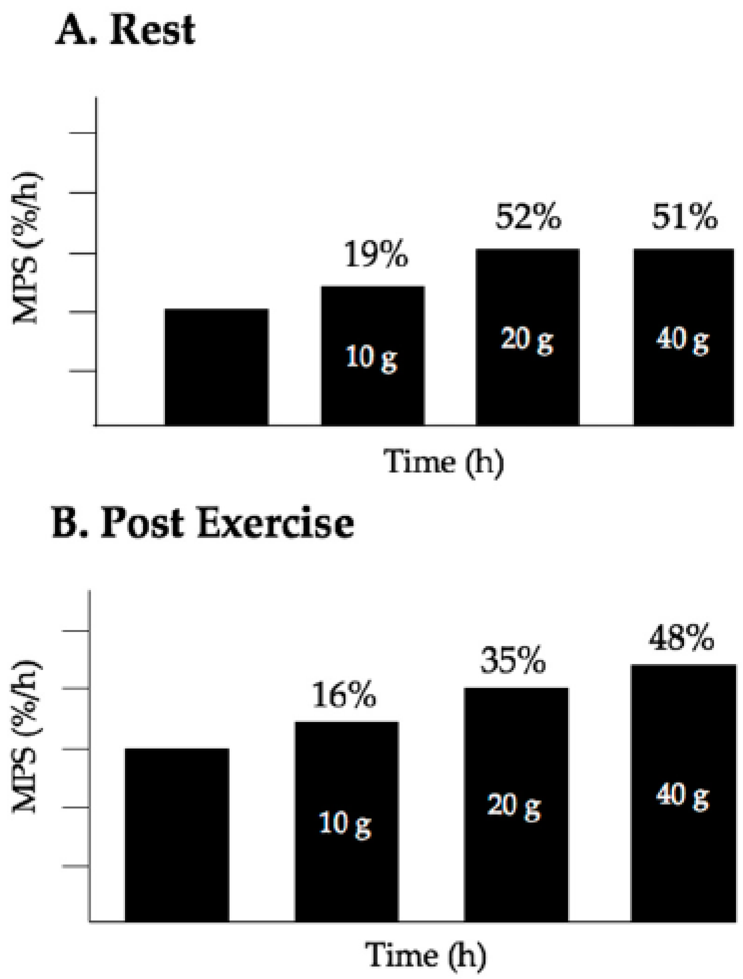
圖片來源：國民營養健康狀況變遷調查 (102-105 年)

A systematic review, meta-analysis and meta-regression of the effect of protein supplementation on resistance training-induced gains in muscle mass and strength in healthy adults

運動後蛋白質建議攝取量



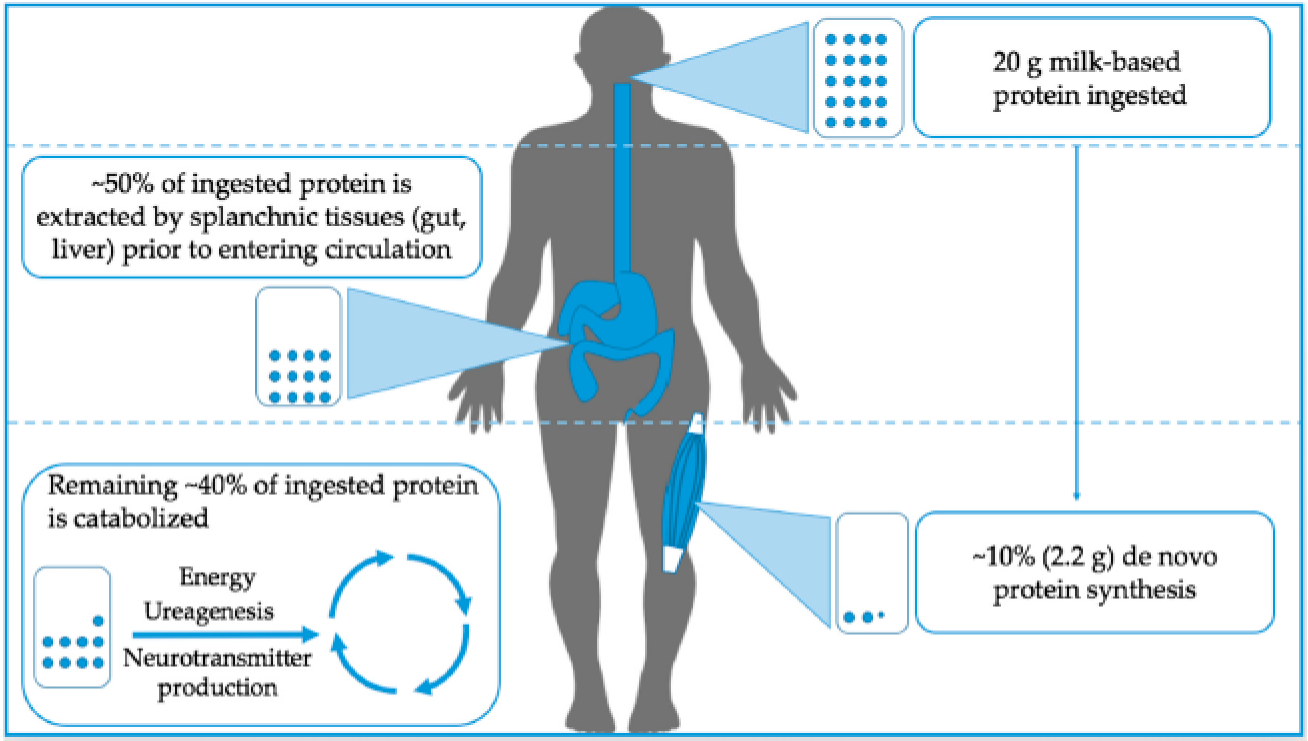


Figure 1. Simplified overview of whole body oral protein utilization at rest. Of the protein ingested, approximately 50% is extracted by splanchnic tissues before entering peripheral circulation. Interestingly, only ~10% of the ingested protein is utilized for skeletal muscle protein synthesis while the rest is catabolized.

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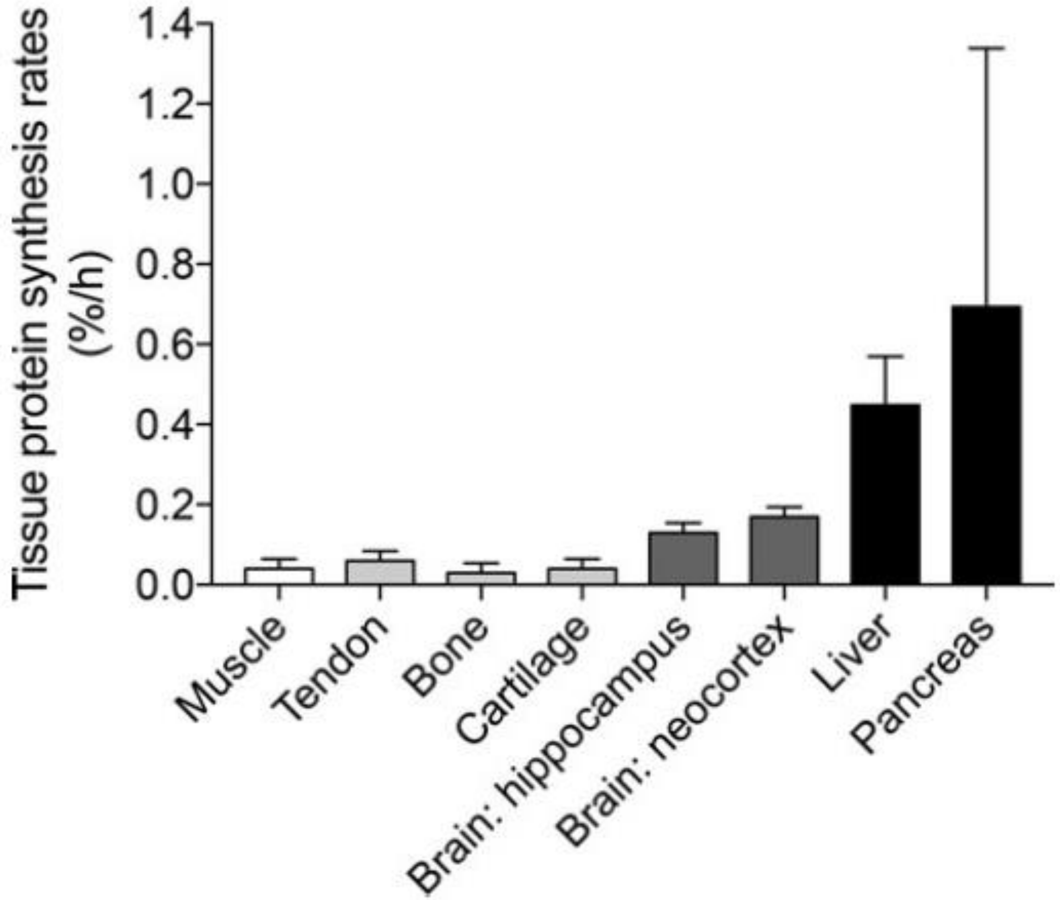
Stokes, T., Hector, A. J., Morton, R. W., McGlory, C., & Phillips, S. M. (2018). Recent perspectives regarding the role of dietary protein for the promotion of muscle hypertrophy with resistance exercise training. Nutrients, 10(2), 180.

一餐蛋白質上限

- It has been proposed that muscle protein synthesis is maximized in young adults with an intake of ~ 20–25 g of a high-quality protein; anything above this amount is believed to be oxidized for energy or transaminated to form urea and other organic acids.

Schoenfeld, B. J., & Aragon, A. A. (2018). How much protein can the body use in a single meal for muscle-building? Implications for daily protein distribution. Journal of the International Society of Sports Nutrition, 15(1), 1-6.

Muscle is not the most important organ

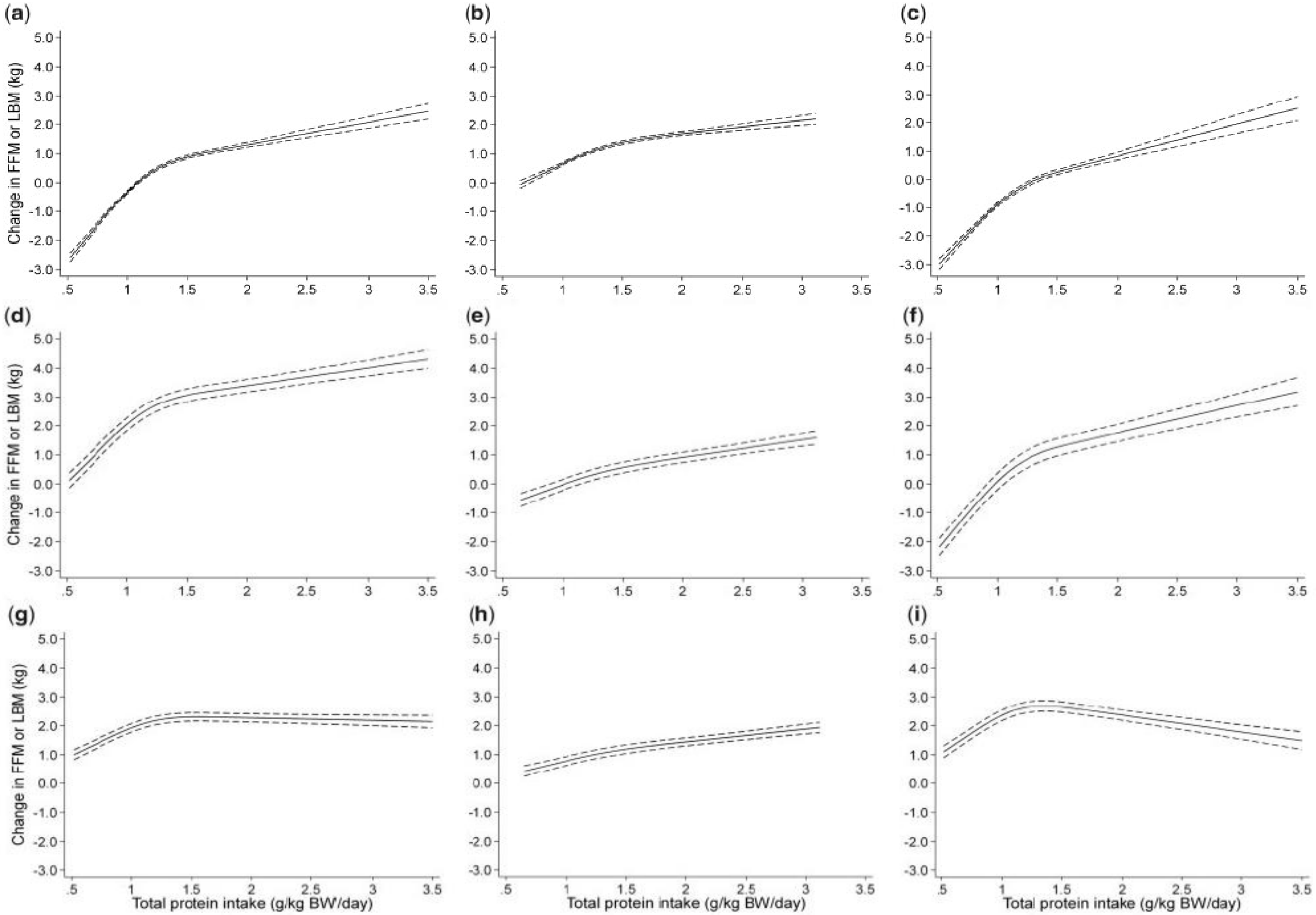


Trommelen, J., & Van Loon, L. (2021). Assessing the whole-body protein synthetic response to feeding in vivo in human subjects. Proceedings of the Nutrition Society, 1-9. doi:10.1017/S0029665120008009

Dose–response relationship between total protein intake and change in lean body mass in each group.

Lean body mass increased by 0.39 kg (95%CI, 0.36–0.41) and 0.12 kg (95%CI, 0.11–0.14) per 0.1 g/kg BW/d increment in total protein intake below and above 1.3 g/ kg BW/d, respectively.

全部　有阻力訓練　無阻力訓練



Tagawa, R., Watanabe, D., Ito, K., Ueda, K., Nakayama, K., Sanbongi, C., & Miyachi, M. (2021). Dose–response relationship between protein intake and muscle mass increase: a systematic review and meta-analysis of randomized controlled trials. Nutrition Reviews, 79(1), 66-75.

Protein Recommendation Based on Goal

目標	蛋白質建議量
一般坐姿生活健康成年人	1.1克
一般坐姿生活健康老年人	1.2克
從事阻力運動新鮮人	1.6克
耐力型運動員	1.3-1.7克
阻力型運動員	1.6-2.2克
健美運動員以體態為首要目標	1.8-2.7克
健美減脂期為保留最多肌肉	≥3.0克

Reference:

1.Nutritional Recommendations for Physique Athletes

2.Should Competitive Bodybuilders Ingest More Protein than Current Evidence-Based Recommendations?

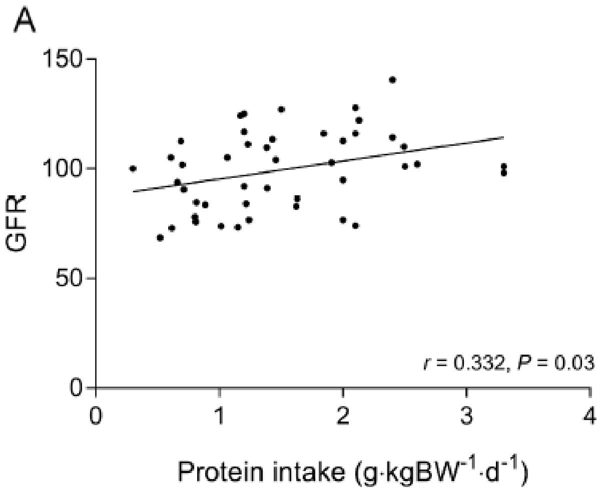
3.Dietary Protein for Training Adaptation and Body Composition Manipulation in Track and Field Athletes

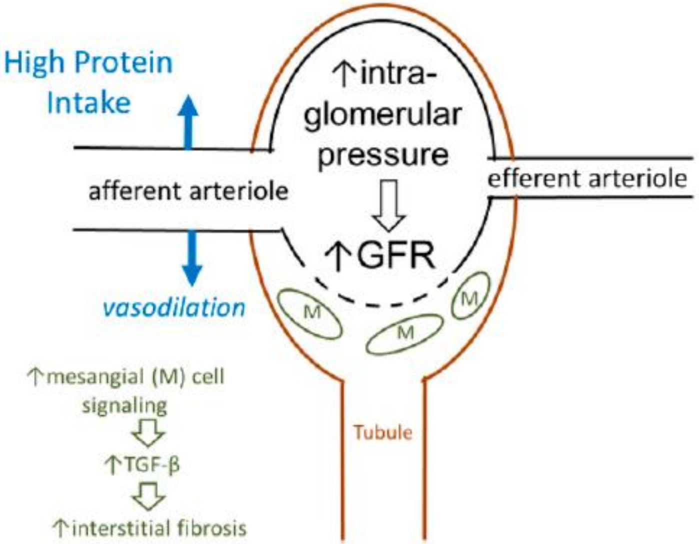
4.Muscle or Nothing! Where Is the Excess Protein Going in Men with High Protein Intakes Engaged in Strength Training?

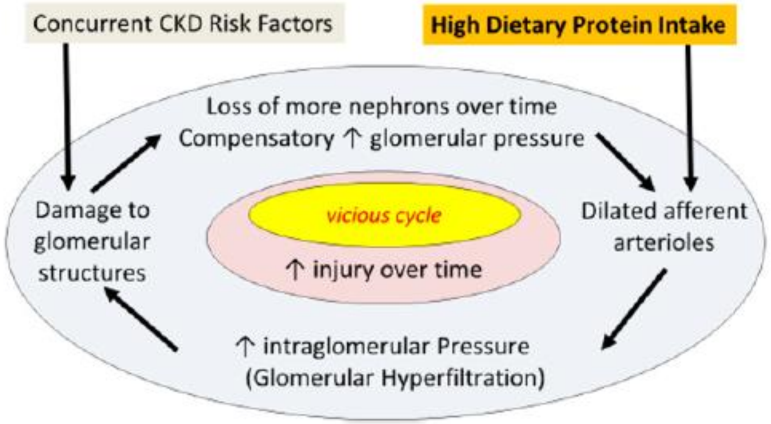
High protein intake and renal function

❌ There is no evidential link that shows that HP intake somehow leads to declines in renal function in otherwise healthy persons and, as our analysis indicates, even in populations with greater risk for declines in renal function such as those with type 2 diabetes.

⭕ High dietary protein intake can cause intraglomerular hypertension, which may result in kidney hyperfiltration, glomerular injury, and proteinuria.





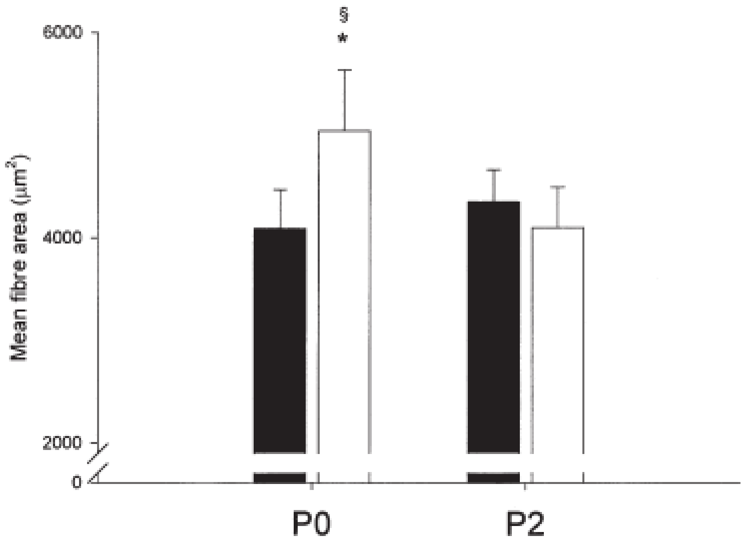


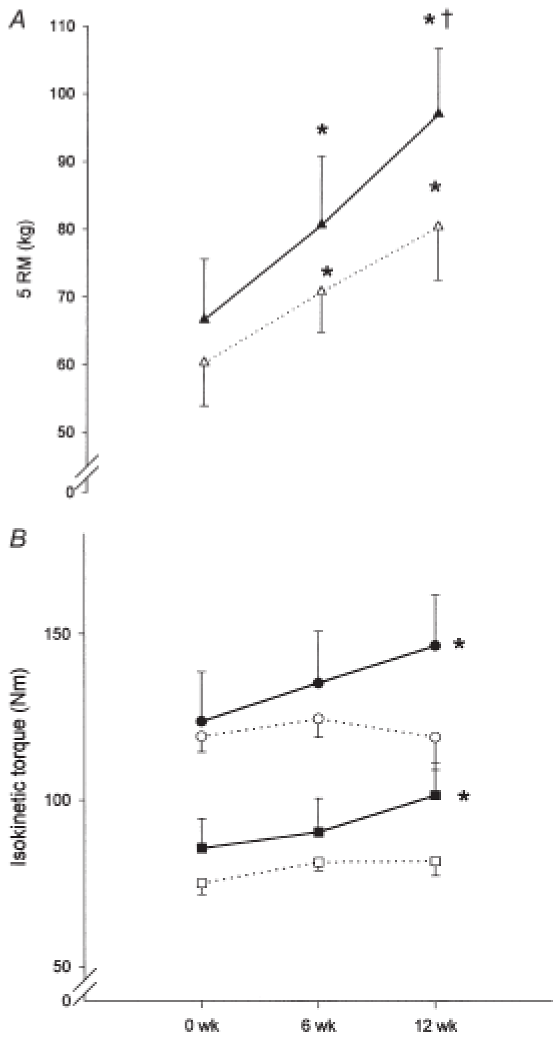
Devries, M. C., Sithamparapillai, A., Brimble, K. S., Banfield, L., Morton, R. W., & Phillips, S. M. (2018). Changes in kidney function do not differ between healthy adults consuming higher-compared with lower-or normal-protein diets: a systematic review and meta-analysis. The Journal of nutrition, 148(11), 1760-1775.

Ko, G. J., Rhee, C. M., Kalantar-Zadeh, K., & Joshi, S. (2020). The effects of high-protein diets on kidney health and longevity. Journal of the American Society of Nephrology, 31(8), 1667-1679.

運動後立即進食是絕對的嗎？

- 運動後黃金30分鐘?
- 運動後晚兩個小時吃，長肌肉和力量效果較差





Esmarck, B., Andersen, J. L., Olsen, S., Richter, E. A., Mizuno, M., & Kjær, M. (2001). Timing of postexercise protein intake is important for muscle hypertrophy with resistance training in elderly humans. The Journal of physiology, 535(1), 301-311.

反對運動後進食窗口

運動後立即進食Meta-analysis：Small to moderate effect

Schoenfeld, B. J., Aragon, A. A., & Krieger, J. W. (2013). The effect of protein timing on muscle strength and hypertrophy: a meta-analysis. Journal of the International Society of Sports Nutrition, 10(1), 53.

1. 強調運動後進食窗口的確存在(但效果量很小)
2. 飲食中的合成效果能長達6小時，強調運動前3-4小時應進食
3. 若進行空腹運動，則運動後立即進食蛋白質非常重要
4. 若目標為最大化肌肉肥大，則運動前後的一餐須間距4-6小時 (meal size)，且需攝取高品質蛋白質(每公斤體重0.4-0.5g)

Schoenfeld, B. J., & Aragon, A. A. (2018). Is there a postworkout anabolic window of opportunity for nutrient consumption? Clearing up controversies. journal of orthopaedic & sports physical therapy, 48(12), 911-914.

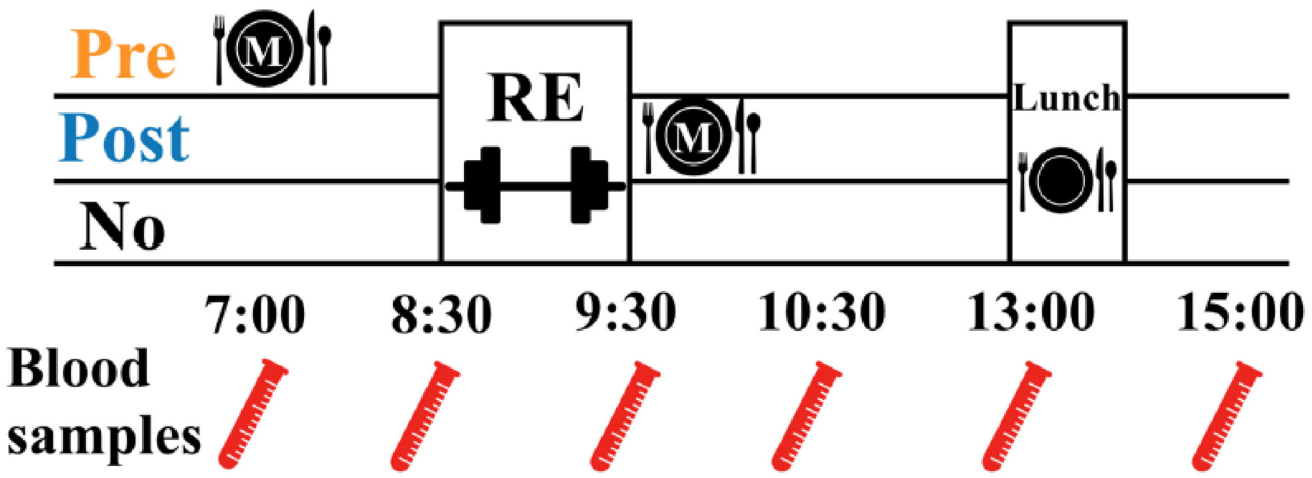
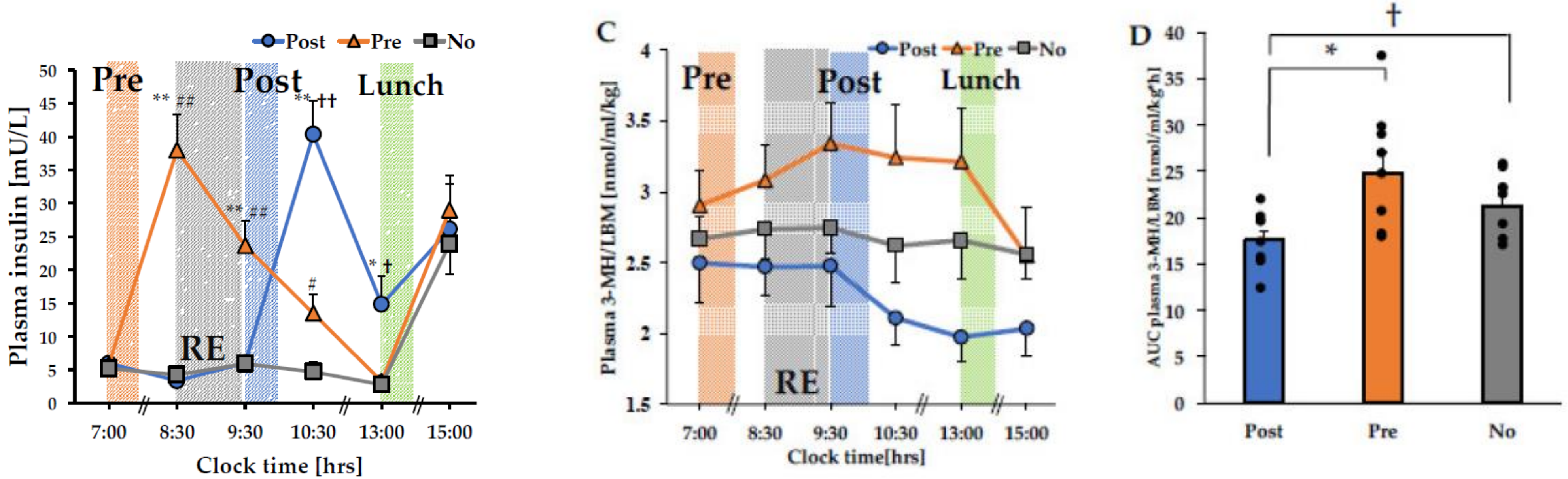


Figure 1. Experimental protocol. RE, resistance exercise; M, meal; Pre, meal intake before RE; Post, meal intake after RE; No, RE without meal intake.



Kume, W., Yasuda, J., & Hashimoto, T. (2020). Acute Effect of the Timing of Resistance Exercise and Nutrient Intake on Muscle Protein Breakdown. Nutrients, 12(4), 1177.

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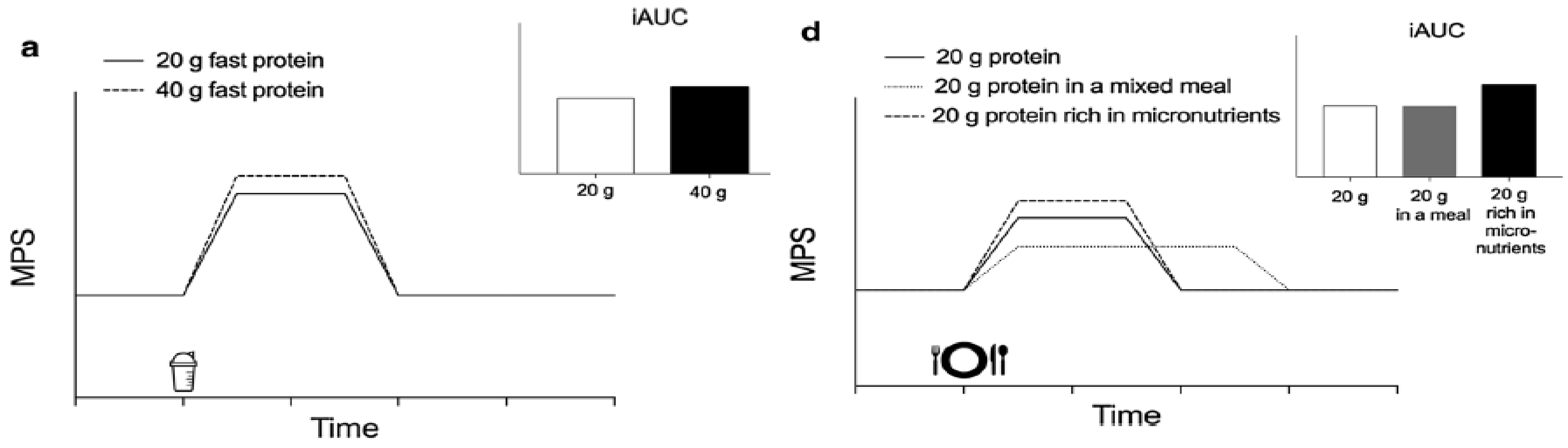
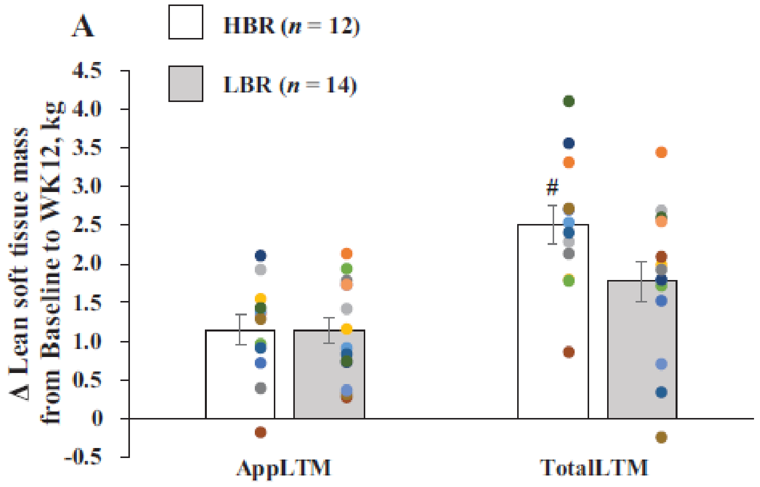
運動後實務上怎麼吃

Trommelen, J., Betz, M. W., & van Loon, L. J. (2019). The muscle protein synthetic response to meal ingestion following resistance-type exercise. Sports Medicine, 49(2), 185-197.



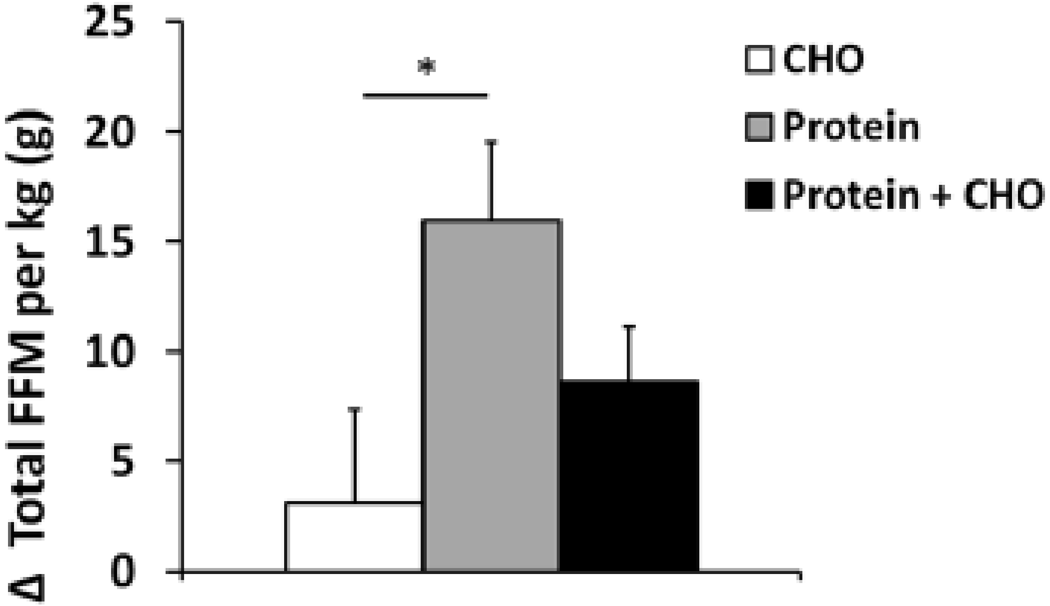
Food Matrix



一日蛋白質平均吃
早餐最容易被忽略

Yasuda, J., Tomita, T., Arimitsu, T., & Fujita, S. (2020). Evenly Distributed Protein Intake over 3 Meals Augments Resistance Exercise–Induced Muscle Hypertrophy in Healthy Young Men. The Journal of Nutrition.

運動後吃甚麼？蛋白質？碳水化合物？



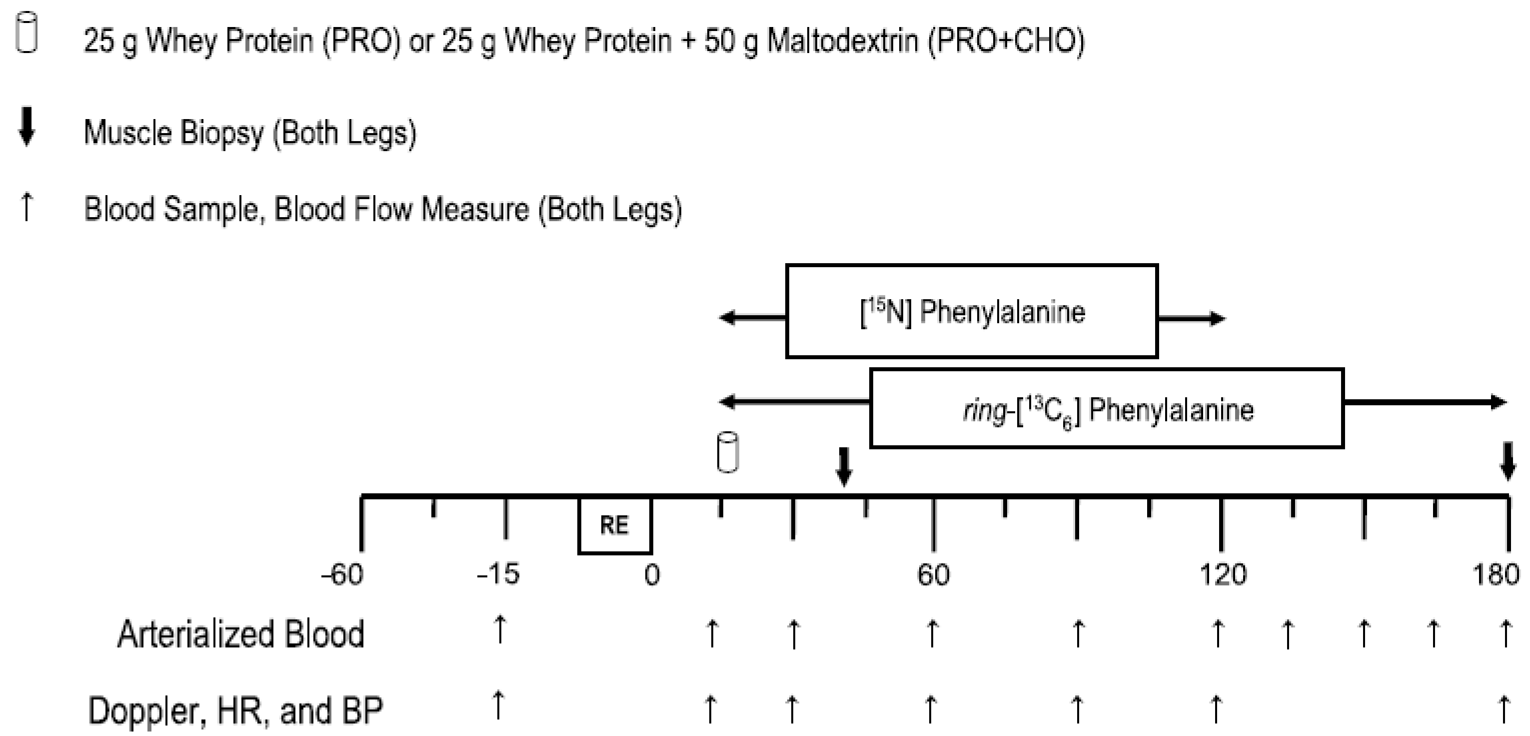
文獻這樣說	1. 運動後只補充蛋白質就能有效刺激蛋白質合成率上升
	2. 攝取蛋白質也會促使胰島素的分泌，這些分泌的量足以抑制蛋白質的分解率

這篇12周的研究指出：

運動後攝取蛋白質加上碳水，對於肌肥大和肌力不會有更好的效果，只要立即單獨攝取蛋白質對於長肌肉就有效。

Hulmi, J. J., Laakso, M., Mero, A. A., Häkkinen, K., Ahtiainen, J. P., & Peltonen, H. (2015). The effects of whey protein with or without carbohydrates on resistance training adaptations. Journal of the International Society of Sports Nutrition, 12(1), 1-13..

運動後吃(蛋白質+碳水化合物) vs (只吃蛋白質)



RE: Unilateral leg extension testing (8~12RM to failure)

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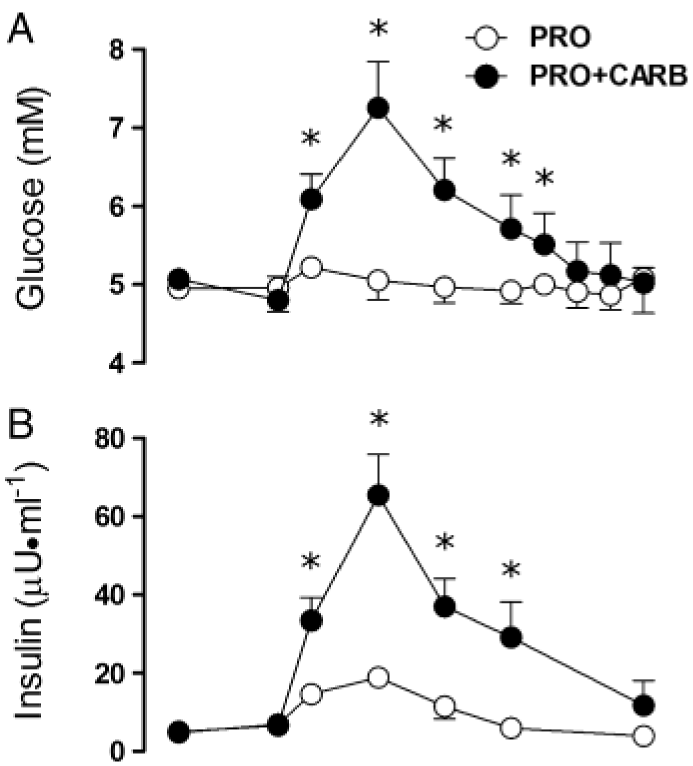
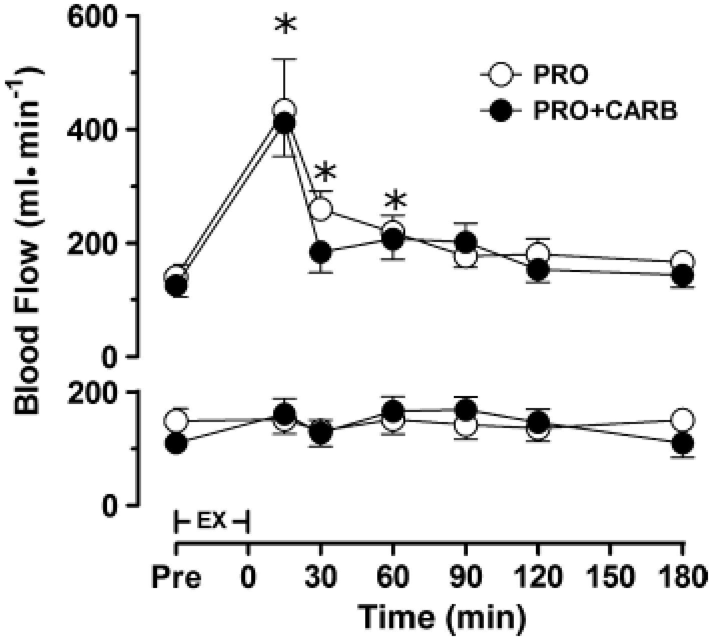
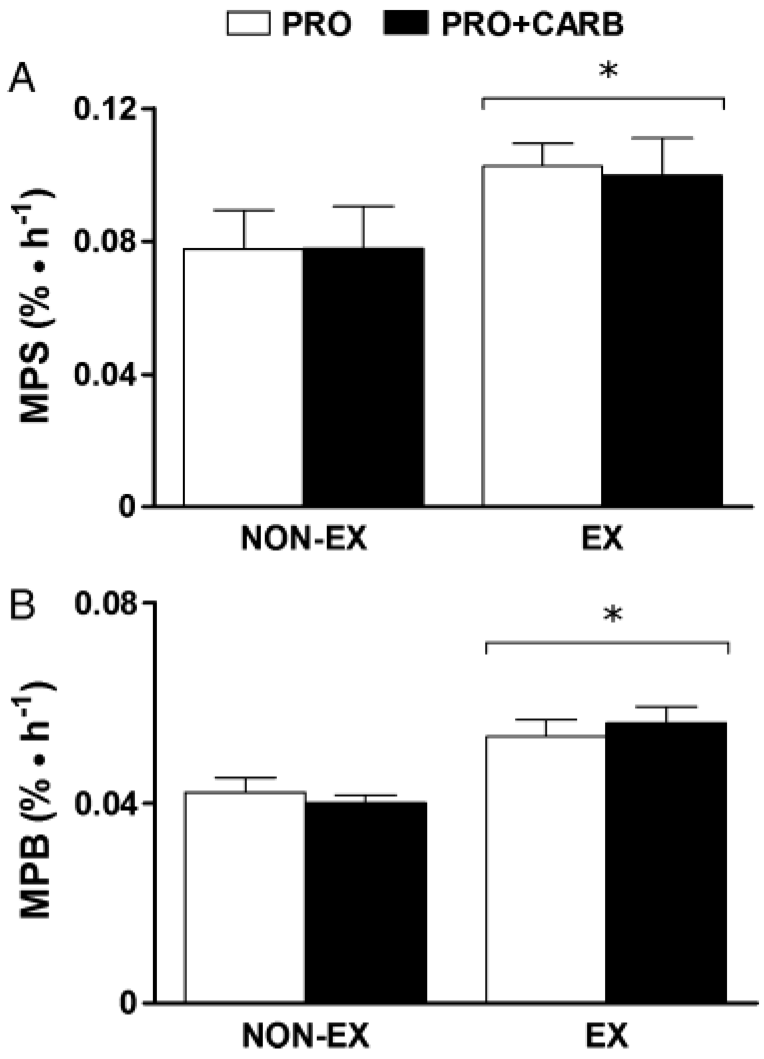
Staples, A. W., Burd, N. A., West, D. W., Currie, K. D., Atherton, P. J., Moore, D. R., ... & Phillips, S. M. (2011). Carbohydrate does not augment exercise-induced protein accretion versus protein alone. Medicine & Science in Sports & Exercise, 43(7), 1154-1161.

兩組運動後的蛋白質合成率和分解率沒有差異







These results suggest that the plasma aminoacidemia and insulinemia in response to 25 g of whey protein alone were sufficient to maximize any insulin-mediated stimulation of MPS.

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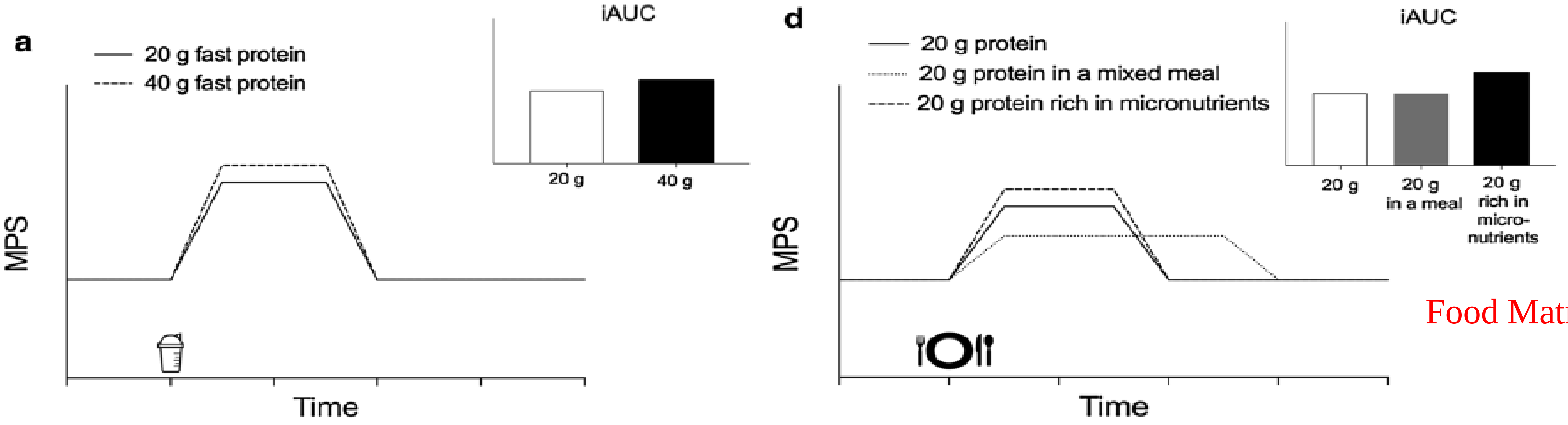
Staples, A. W., Burd, N. A., West, D. W., Currie, K. D., Atherton, P. J., Moore, D. R., ... & Phillips, S. M. (2011). Carbohydrate does not augment exercise-induced protein accretion versus protein alone. Medicine & Science in Sports & Exercise, 43(7), 1154-1161.

運動後實務上怎麼吃？乳清？雞胸？



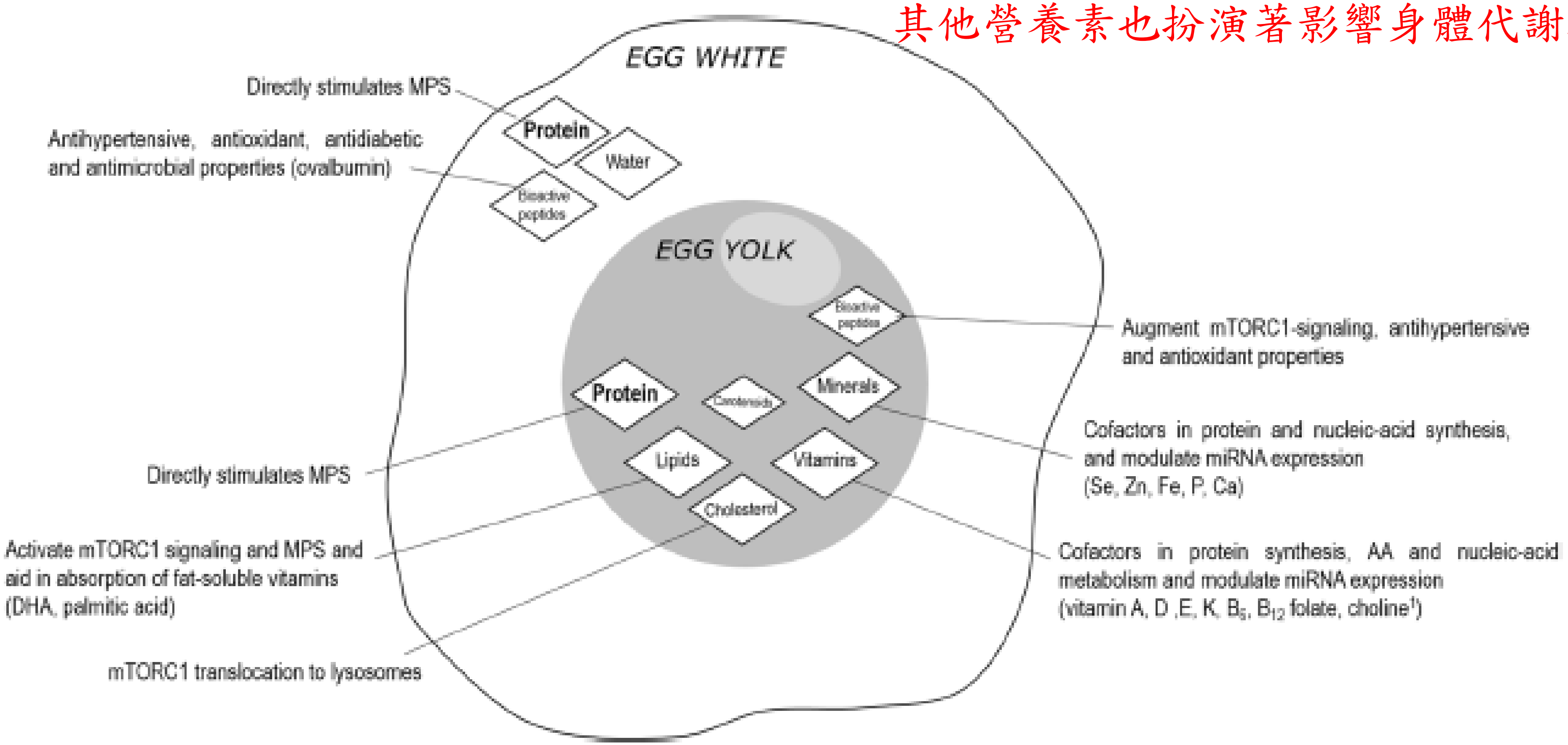
Food Matrix

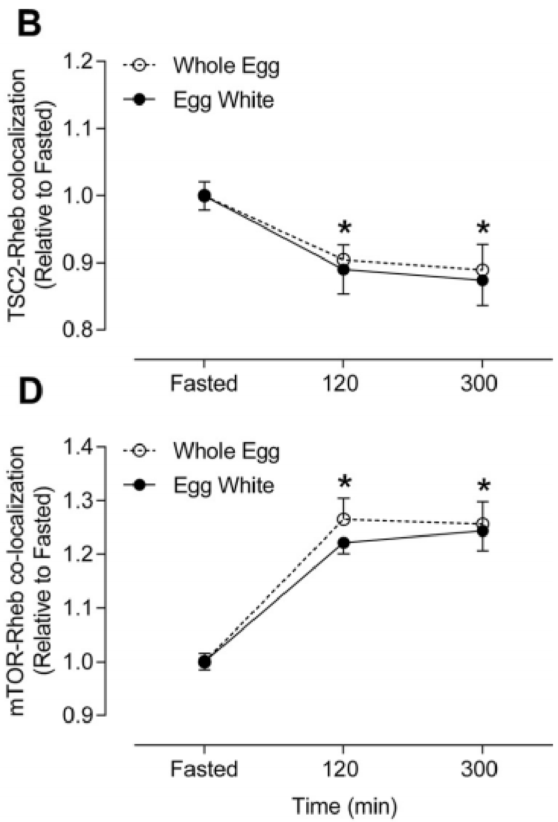
Trommelen, J., Betz, M. W., & van Loon, L. J. (2019). The muscle protein synthetic response to meal ingestion following resistance-type exercise. Sports Medicine, 49(2), 185-197.

Yasuda, J., Tomita, T., Arimitsu, T., & Fujita, S. (2020). Evenly Distributed Protein Intake over 3 Meals Augments Resistance Exercise–Induced Muscle Hypertrophy in Healthy Young Men. The Journal of Nutrition.

蛋白與全蛋實驗

Nutrient and Protein-dense foods
其他營養素也扮演著影響身體代謝路徑的重要角色





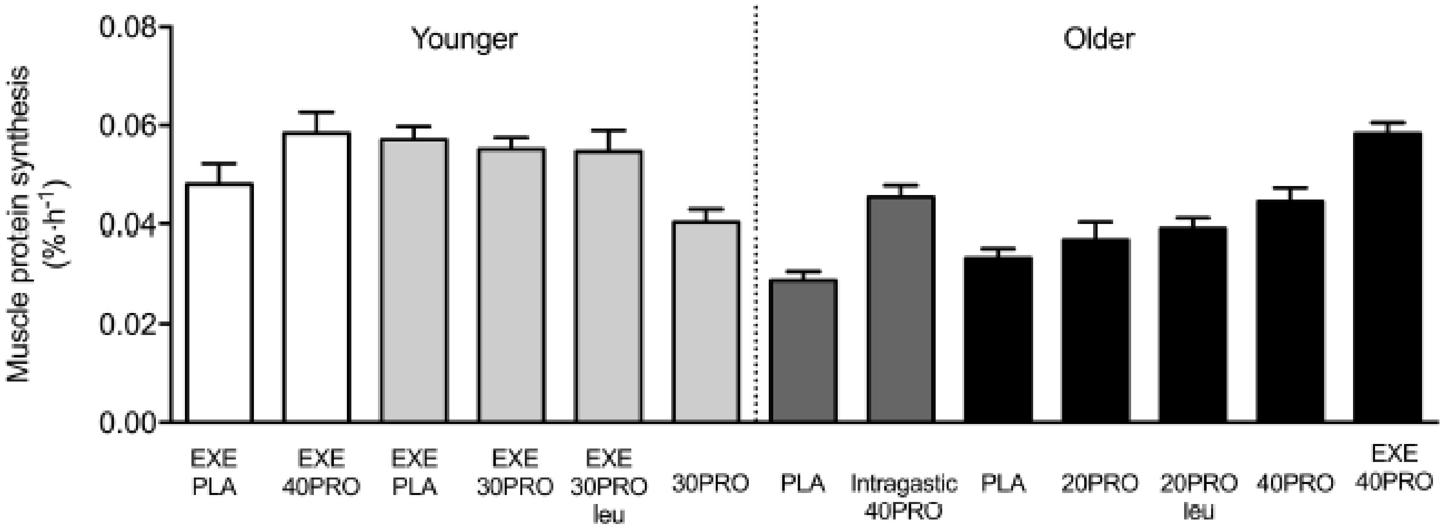
Abou Sawan, S., van Vliet, S., West, D. W., Beals, J. W., Paluska, S. A., Burd, N. A., & Moore, D. R. (2018). Whole egg, but not egg white, ingestion induces mTOR colocalization with the lysosome after resistance exercise. American Journal of Physiology-Cell Physiology, 315(4), C537-C543.

Van Vliet, S., Shy, E. L., Abou Sawan, S., Beals, J. W., West, D. W., Skinner, S. K., ... & Burd, N. A. (2017). Consumption of whole eggs promotes greater stimulation of postexercise muscle protein synthesis than consumption of isonitrogenous amounts of egg whites in young men. The American journal of clinical nutrition, 106(6), 1401-1412.

Pre-sleep protein ingestion

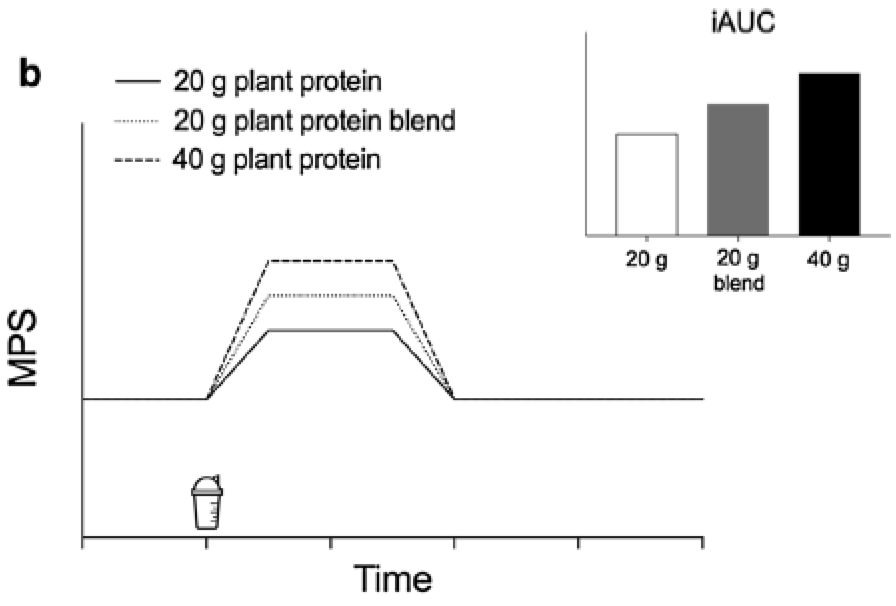
- Protein ingestion before sleep has been hypothesized to represent an effective nutritional strategy to increase daily protein intake

1. 並非是因為時間點的因素，主要與總蛋白質攝取增加有關。
2. 睡前補充蛋白質，是一個增加總蛋白質攝取量的方法之一 (均能被有效地消化和吸收)



Snijders, T., Trommelen, J., Kouw, I. W., Holwerda, A. M., Verdijk, L. B., & Van Loon, L. J. (2019). The impact of pre-sleep protein ingestion on the skeletal muscle adaptive response to exercise in humans: An update. Frontiers in nutrition, 6, 17.

植物性蛋白



- Prof. Heidi M. Lynch 隨機給予48位受試者含有等量Leucine (2g)之大豆蛋白 (26g)與乳清蛋白 (19g)

	分離乳清蛋白	分離大豆蛋白
Leucine (mg)	1997	1967
Isoleucine (mg)	1243	1233
Valine (mg)	1067	1188

- 訓練：12周全身漸進式阻力訓練(3次/周)
- 蛋白補充時機：運動後立即(非運動日則選在餐與餐之間)

	分離乳清蛋白	分離大豆蛋白
瘦體重改變量 (kg)	1.5	1.2
脂肪改變量 (kg)	-0.6	-0.9
力量改變量 (Nm)	30.5	19.7

兩組均沒顯著差異

- 結論：植物性蛋白也能刺激肌肉成長，且不輸給動物性蛋白，但為了要使Leucine含量一致，植物性蛋白必須吃的稍多一些。

ISSN建議之Leucine攝取量為700-3000 mg

Lynch, H. M., Buman, M. P., Dickinson, J. M., Ransdell, L. B., Johnston, C. S., & Wharton, C. M. (2020). No Significant Differences in Muscle Growth and Strength Development When Consuming Soy and Whey Protein Supplements Matched for Leucine Following a 12 Week Resistance Training Program in Men and Women: A Randomized Trial. International Journal of Environmental Research and Public Health, 17(11), 3871.

Fat

- Dietary fat intake is necessary for hormone production and to ensure the absorption of fat-soluble vitamins (i.e., vitamins A, D, E, and K).
- Furthermore, n-3 and n-6 fatty acids are essential nutrients.
- Therefore, it is recommended that fat intake should not fall below 20% of total caloric intake for extended periods of time and should likely stay within the AMDR range of **20–35%** of total caloric intake.

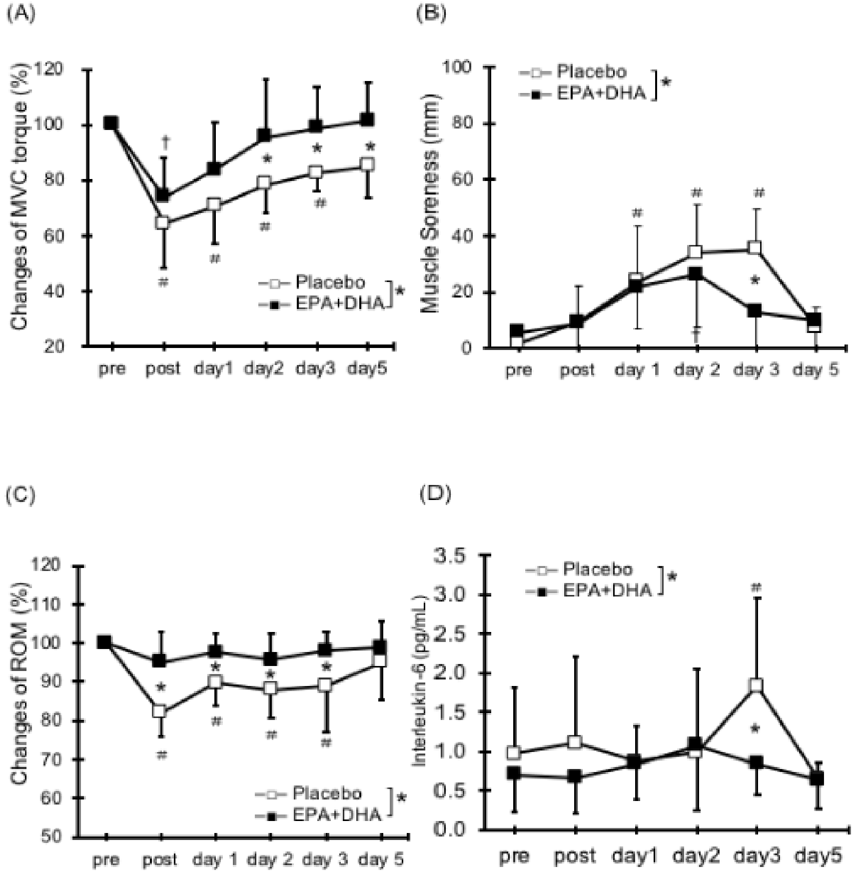
Omega-3 fatty acids may have benefits after exercise

- Benefits:

1. Some positive effects of EPA and DHA have been observed on ECC-induced nerve and muscle damage (muscle strength deficit, DOMS, reduced ROM, and muscle swelling), while some results are not consistent.
2. EPA and DHA may have positive effects on muscle mass under wasting condition, but it is unclear with regard to training.

- Possible mechanism:

1. The ingestion of EPA and DHA can inhibit muscle mass decreases in animal.
2. Previous studies showed that omega-3 ingestion activated the Akt-mTOR-p70S6K pathway, which is extremely important in protein synthesis, in an animal experiment.
3. In addition, an investigation using dystrophin-deficit mouse found that EPA and DHA intake increased the number of activated satellite cells.
4. Similarly, DHA-enriched diet cause increases in insulin-like growth factor-1 (IGF-1) mRNA expression, Akt-mTOR-p70S6K pathway, and the fractional synthesis rate in pigs.



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Ochi, E., & Tsuchiya, Y. (2018). Eicosapentaenoic acid (EPA) and docosahexaneoic acid (DHA) in muscle damage and function. *Nutrients*, *10*(5), 552.

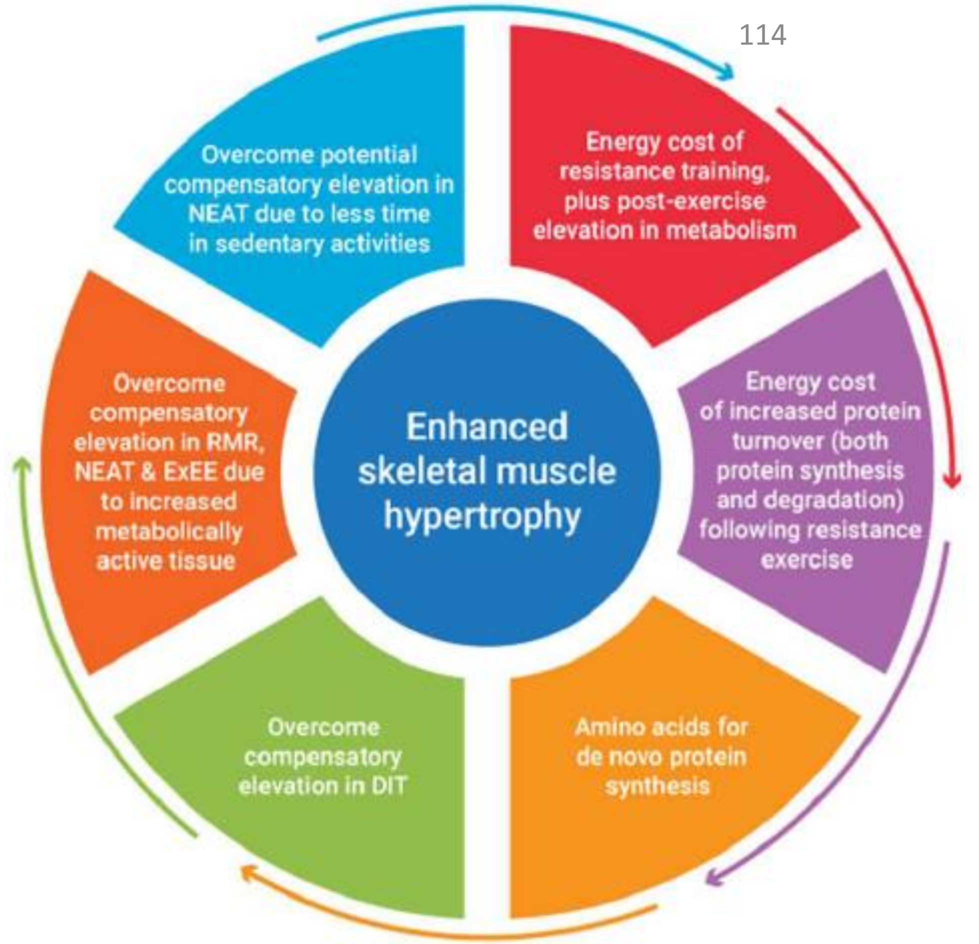
Physique Athletes

Caloric Surplus Recommendation

Table 1
Energy surplus guideline summary

Training status	Magnitude of the energy surplus	Nature of the energy surplus	Notes & caveats
Untrained/ novice or deconditioned	Approximately 20–40% above maintenance needs (~500–1,000 kcal)	Greater potential benefit of a predominance of carbohydrate due to higher total energy surplus capacity. Surplus should include a minimum protein dose of approximately 20–40 g (or at least ~0.4 g/kg of total bodyweight).	First and foremost, a caloric surplus for muscle gain must be built on a foundation of sufficient total daily protein and energy intake. In general, for optimizing high-intensity fueling requirements of progressive resistance training, an energy surplus should center around higher carbohydrate intakes. However, increased proportions of protein can be used depending on how cautiously one wants to court the potential for concurrent fat gain. More advanced trainees closer to their potential have less room for surplus energy partitioning into lean tissue, and thus may choose to use protein-focused surpluses. Regardless of training status, individuals cautiously avoiding fat gain may also benefit from this tactic.
Trained/more advanced; closer to maximum potential	Approximately 10–20% above maintenance needs (~250–500 kcal)	Lesser potential benefit of carbohydrate predominance due to lower total energy surplus capacity. Surplus should include a minimum protein dose of approximately 20–40 g (or at least ~0.4 g/kg of total bodyweight).	

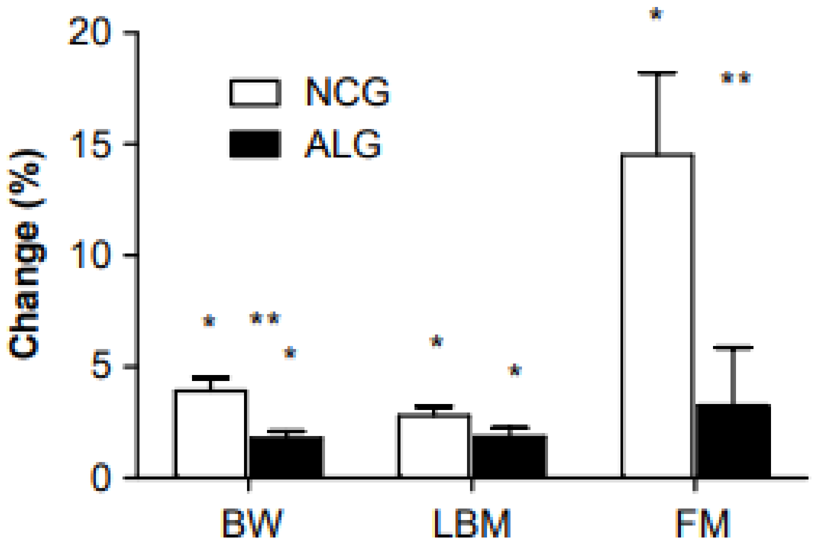
Aragon, A. A. and B. J. Schoenfeld (2020). "Magnitude and Composition of the Energy Surplus for Maximizing Muscle Hypertrophy Implications for Bodybuilding and Physique Athletes." Strength and Conditioning Journal.



Practitioners are advised to take a conservative approach to creating an energy surplus, within the range of 1,500–2,000 kJ·day^{-1}, to minimize FM gains, with regular review of body composition and functional capacities like strength to further personalize dietary intake.

Slater, G. J., Dieter, B. P., Marsh, D. J., Helms, E. R., Shaw, G., & Iraki, J. (2019). Is an energy surplus required to maximize skeletal muscle hypertrophy associated with resistance training. Frontiers in nutrition, 6, 131.

Clean bulk vs dirty bulk



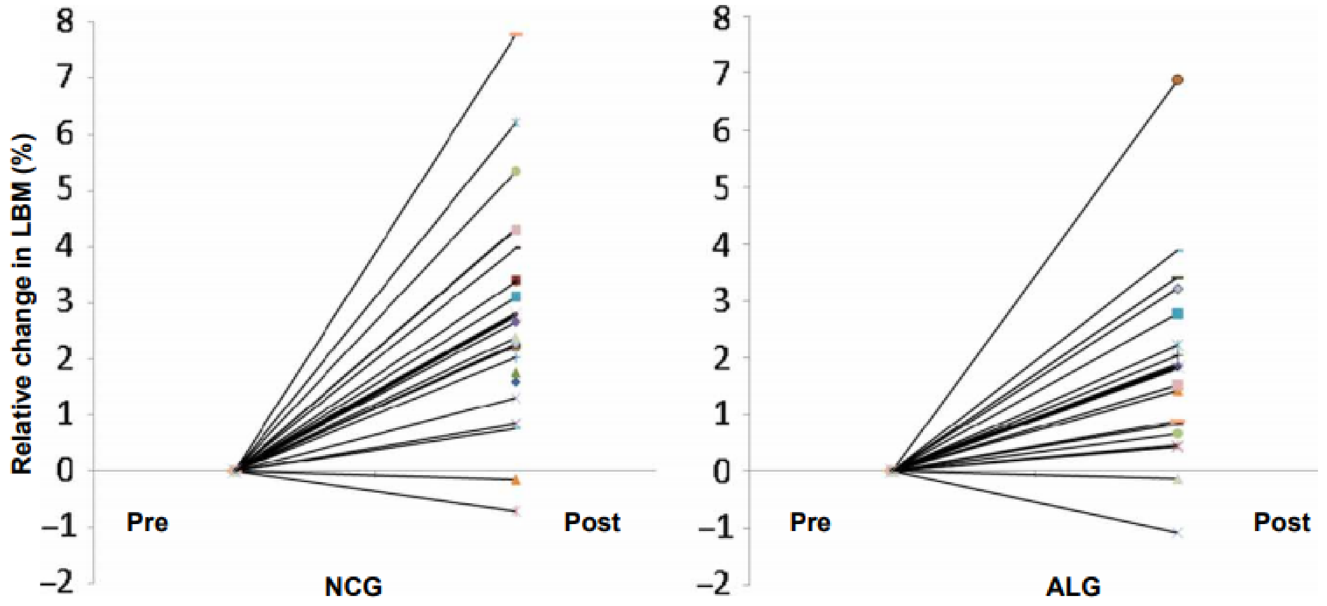


Figure 3. Relative changes in lean body mass (LBM) for athletes in the nutritional counseling group (NCG) and the ad libitum group (ALG).

Considering the results in previous study, we speculate that 200~300 kcal per day surplus may be more appropriate than 500 kcal per day for the elite athlete if an increase in FM is not advantageous for the athlete or the sports specific performance.

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Garthe, I., Raastad, T., Refsnes, P. E., & Sundgot-Borgen, J. (2013). Effect of nutritional intervention on body composition and performance in elite athletes. European journal of sport science, 13(3), 295-303.

Periodized Nutritional Plan for change of training volume and body mass

Mota, 2019

Table
Evidence-based recommendations for nutrition modifications geared to accommodate alterations in training load and different body mass–based goals of the athlete

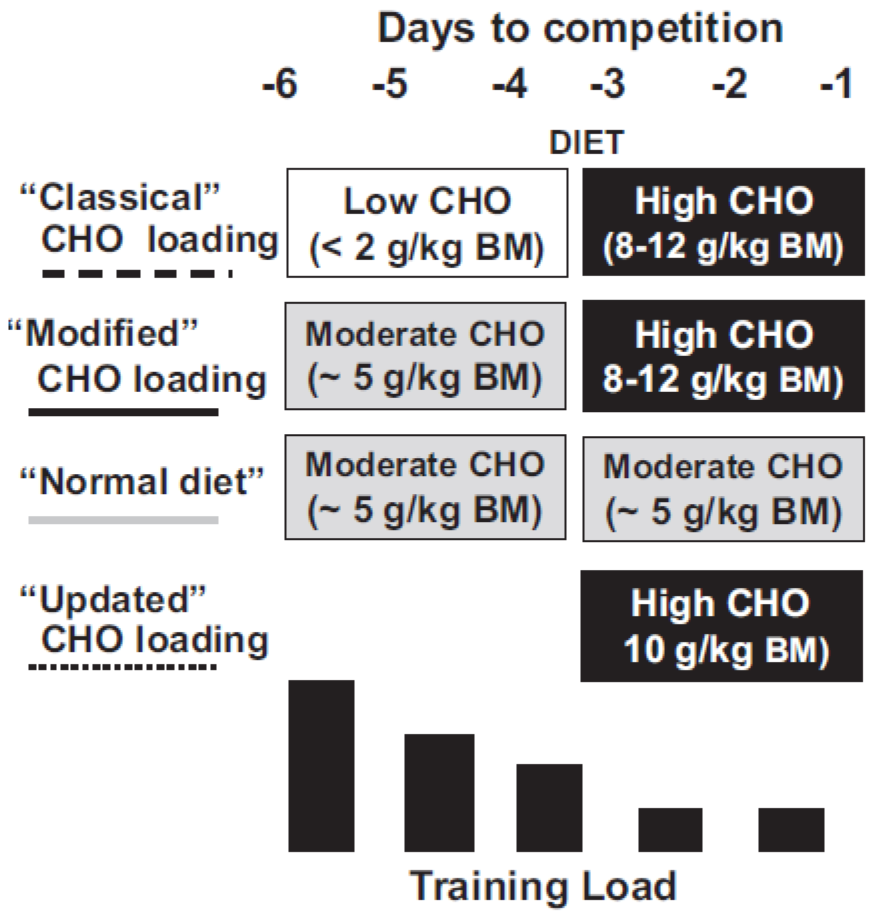
	Decreasing body mass	Maintaining body mass	Increasing body mass
Decreased training volume	Decreased calorie intake sufficient to lose ~0.25–0.75% of body mass per week (larger caloric decrease to reflect decreased training volume) Minimum EA, 30 $kcal \cdot kg^{-1}$ FFM CHO, 4–5 $g \cdot kg$ body $mass^{-1}$ PRO, 1.6–2.4 $g \cdot kg$ body $mass^{-1}$	Slight decrease in caloric intake to reflect decreased training volume CHO, 4–7 $g \cdot kg$ body $mass^{-1}$ PRO, 1.2–1.8 $g \cdot kg$ body $mass^{-1}$	Not recommended (Not ideal for skeletal muscle hypertrophy and/or increased risk of fat accumulation)
No change in training volume	Decreased caloric intake sufficient to lose ~0.25–0.75% of body mass per week Minimum EA, 30 $kcal \cdot kg^{-1}$ FFM CHO, 4–5 $g \cdot kg$ body $mass^{-1}$ PRO, 1.6–2.4 $g \cdot kg$ body $mass^{-1}$	No change in calorie intake CHO, 4–7 $g \cdot kg$ body $mass^{-1}$ PRO, 1.2–1.8 $g \cdot kg$ body $mass^{-1}$	Increased calorie intake to increase body mass 0.1–0.25% per week CHO, 6–7 $g \cdot kg$ body $mass^{-1}$ PRO, 1.2–1.8 $g \cdot kg$ body $mass^{-1}$
Increased training volume	Not recommended (increased risk of overtraining or injury)	Slight increase in caloric intake to reflect increase in volume CHO, 4–7 $g \cdot kg$ body $mass^{-1}$ PRO, 1.2–1.8 $g \cdot kg$ body $mass^{-1}$	Increased calorie intake to increase body mass 0.1–0.25% per week (larger caloric increase to reflect increase in training volume) CHO, 6–7 $g \cdot kg$ body $mass^{-1}$ PRO, 1.2–1.8 $g \cdot kg$ body $mass^{-1}$

Assumes neutral caloric balance at a current level of training volume.

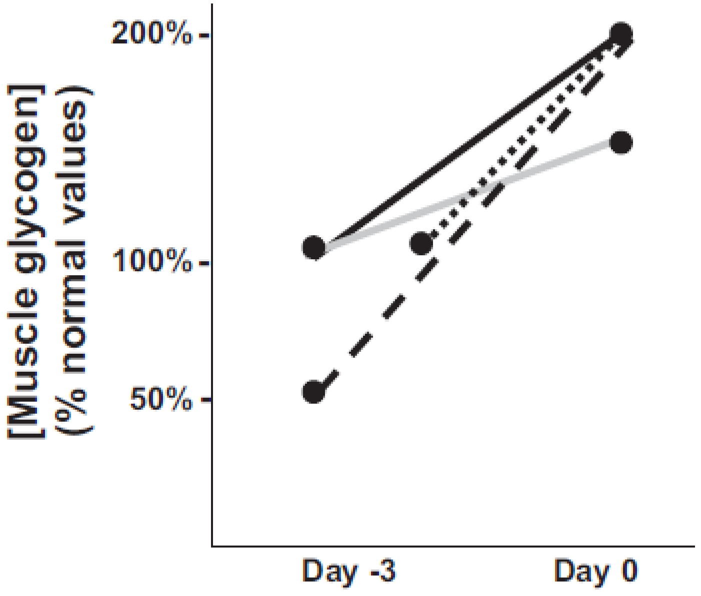
CHO = carbohydrate; EA = energy availability; FFM = fat-free mass; PRO = protein.

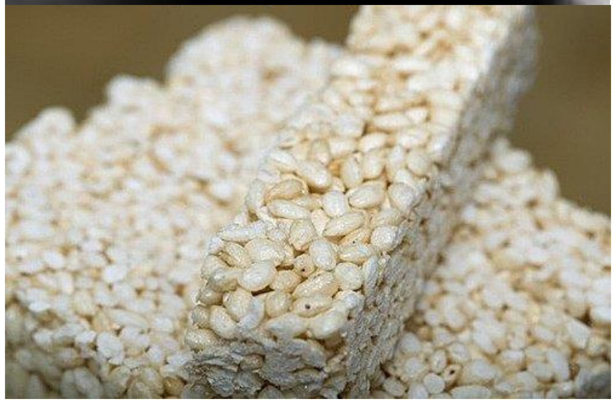
賽前飲食調理-改良式肝醣超補

Manipulation of diet and training



Effect on glycogen storage





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Burke, L. M., van Loon, L. J., & Hawley, J. A. (2017). Postexercise muscle glycogen resynthesis in humans. Journal of Applied Physiology, 122(5), 1055-1067.

Glycogen supercompensation is due to increased number, not size, of glycogen particles in human skeletal muscle

- Using transmission electron microscopy to inspect individual glycogen particles visually, we show tha achieved by increasing the nu submaximal sizes. This might b particles can be used fast, bec impair utilization rate.

New Findings

- **What is the central question of this study?**

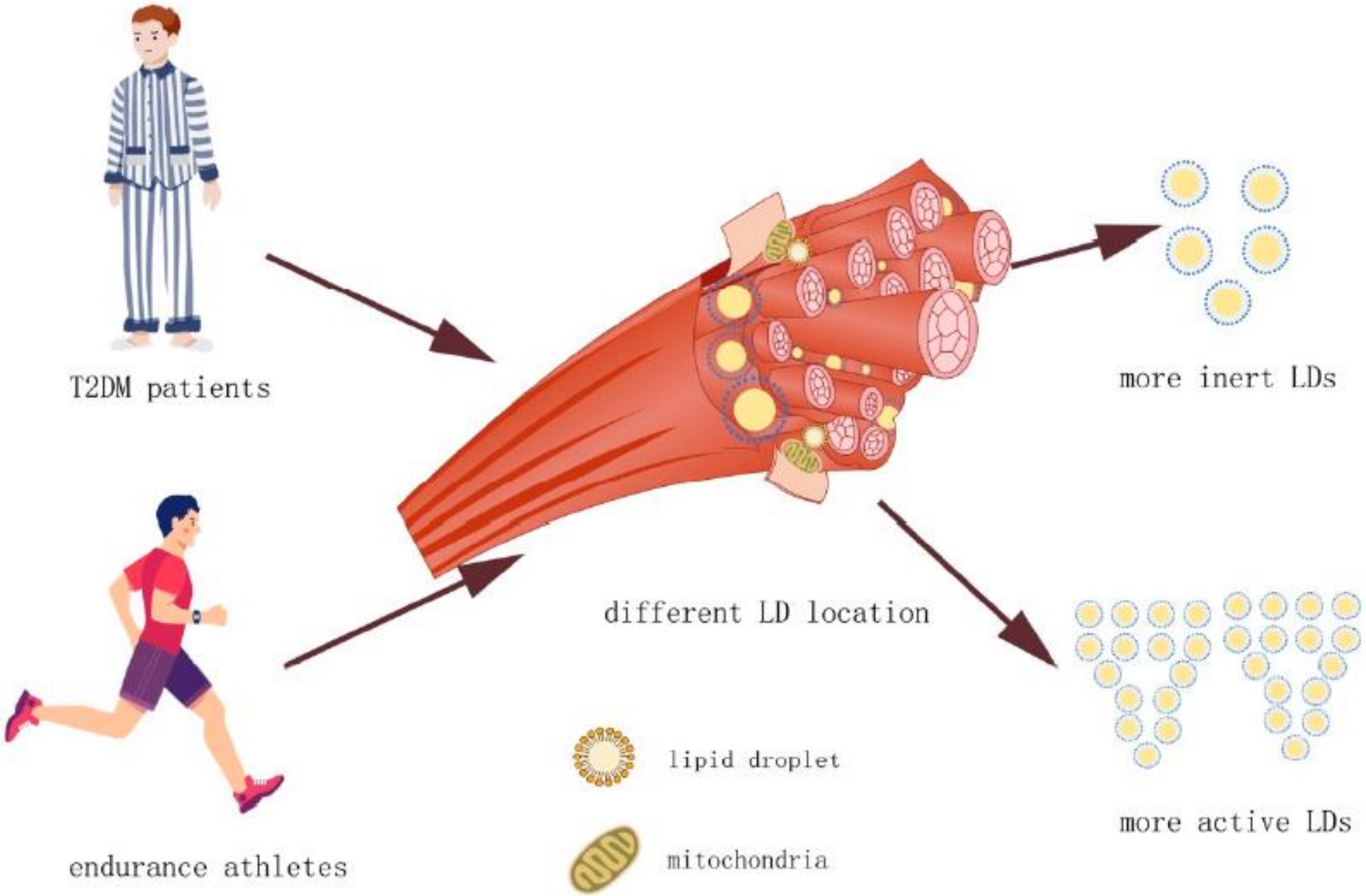
  Glycogen supercompensation after glycogen-depleting exercise can be achieved by consuming a carbohydrate-enriched diet, but the associated effects on the size, number and localization of intramuscular glycogen particles are unknown.

- **What is the main finding and its importance?**

  Using transmission electron microscopy to inspect individual glycogen particles visually, we show that glycogen supercompensation is achieved by increasing the number of particles while keeping them at submaximal sizes. This might be a strategy to ensure that glycogen particles can be used fast, because particles that are too large might impair utilization rate.

Jensen, R., Ørtenblad, N., Stausholm, M. L. H., Skjærbæk, M. C., Larsen, D. N., Hansen, M., ... & Nielsen, J. (2021). Glycogen supercompensation is due to increased number, not size, of glycogen particles in human skeletal muscle. *Experimental Physiology*.

Athlete’s Paradox



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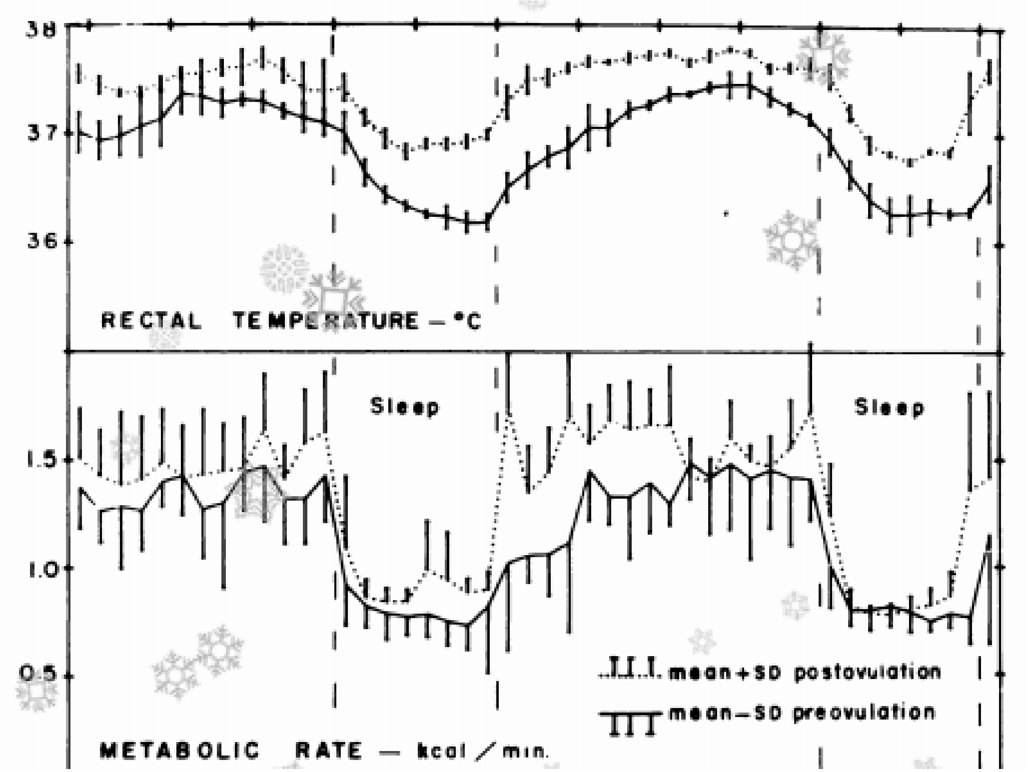
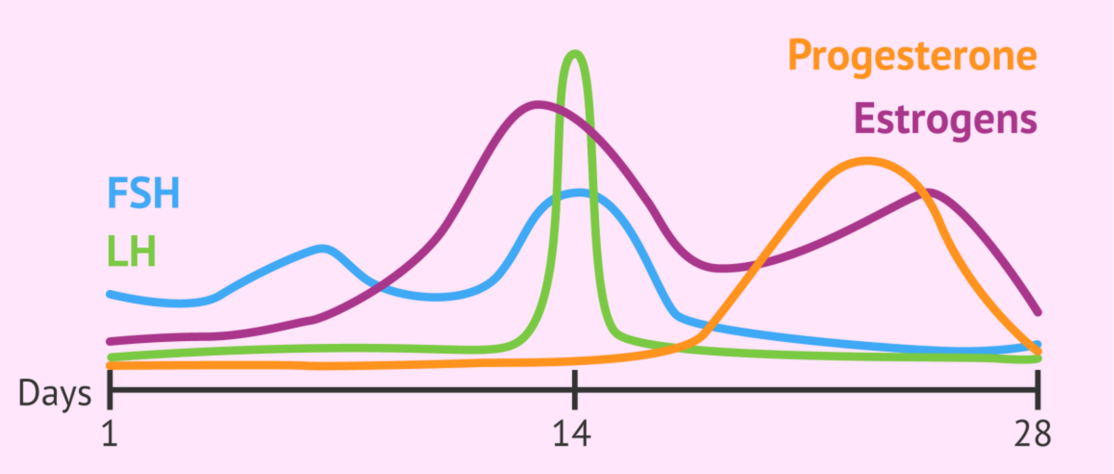
Li, X., Li, Z., Zhao, M., Nie, Y., Liu, P., Zhu, Y., & Zhang, X. (2019). *Skeletal muscle lipid droplets and the athlete’s paradox. Cells, 8(3), 249..*

Female have higher BMR and body temperature after ovulation.



Results

Thirty English-language studies published between 1930 and December 2019 were included in the systematic review, and 26 studies involving 318 women were included in the meta-analysis. Overall, there was a small but significant effect favoring increased RMR in the luteal phase (ES = 0.33; 95% CI = 0.17, 0.49, $p < 0.001$).

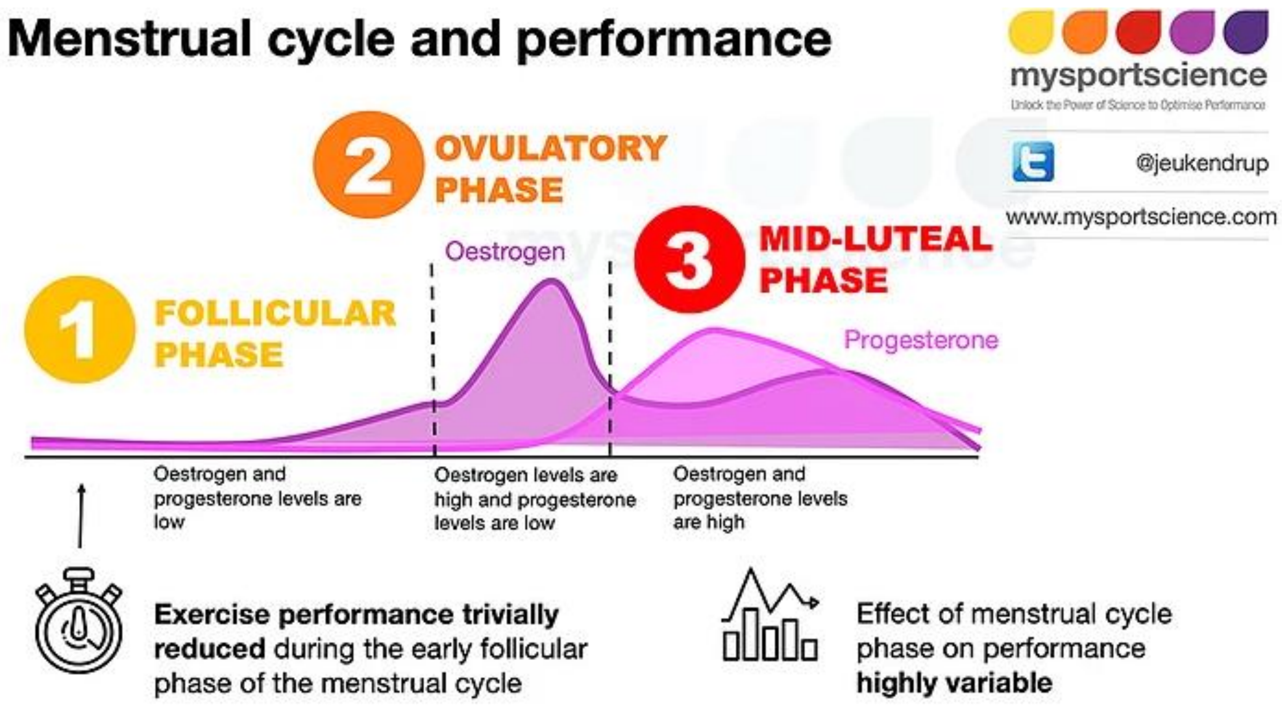


Eight of the 10 women showed increases of 8-16% during the 14-day luteal phase following ovulation.

Webb P. 24-hour energy expenditure and the menstrual cycle. Am J Clin Nutr. 1986 Nov;44(5):614-9. doi: 10.1093/ajcn/44.5.614. PMID: 3766447.

Benton, M. J., Hutchins, A. M., & Dawes, J. J. (2020). Effect of menstrual cycle on resting metabolism: A systematic review and meta-analysis. PloS one, 15(7), e0236025.

Performance slightly reduced during follicular phase



Almost all athletes (93%) reported menstrual cycle-related symptoms. Thirty-three per cent perceived heavy menstrual bleeding and 67% considered these symptoms impaired their performances.

Findlay, R. J., Macrae, E. H., Whyte, I. Y., Easton, C., & Forrest, L. J. (2020). How the menstrual cycle and menstruation affect sporting performance: experiences and perceptions of elite female rugby players. British Journal of Sports Medicine.

Considerations for female athletes

- The menstrual cycle influence the metabolic rate and total daily energy expenditure (TDEE) in women.
- The sleeping metabolic rate is 6.1–7.7% higher during **the luteal phase** of the menstrual cycle than the follicular phase, and TDEE is 2.5– 11.5% **higher**.
- In addition, inadequate caloric intake has been directly associated with menstrual cycle dysfunction.
- Other considerations for female athletes and nutritional periodization suggest fasting before exercise for the female athlete may blunt fat oxidation and metabolic rate, more so than men.
- Women may also be less responsive to glycogen supercompensation methods, requiring higher carbohydrate needs (8 g · kg body mass^{-1}) when glycogen saturation is desired

體重/體脂過低也不健康

過低的體重或體脂容易造成健康的負面影響
對女生尤其重要：月經失調、骨質流失(女性運動員三症等)、心血管疾病、胃腸道併發症等

此低體重體脂導致的女性月經失調

稱為功能性下丘腦閉經 Functional hypothalamic amenorrhea

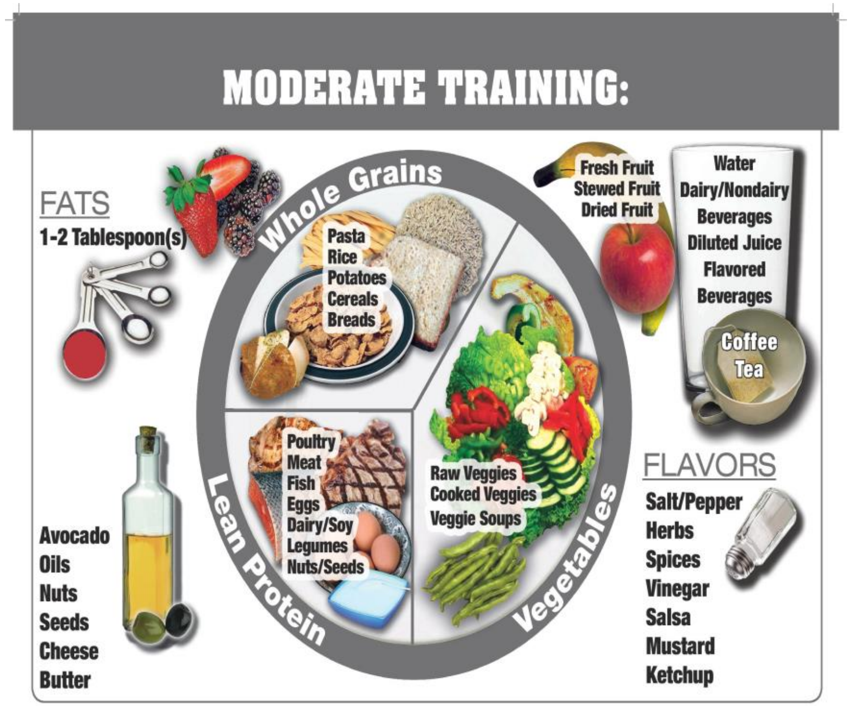
→由過低體重與過多的運動量造成

維持正常的月經週期研究建議體脂約為22%
低於17%會造成停經的現象

人體中存在許多組織是由脂肪組成，例如：神經組織、骨髓、細胞膜

正常的年輕男/女性的體脂肪應為12-15% / 25-28%

ATHLETE'S PLATE



The Athlete's Plates are a collaboration between the United States Olympic Committee Sport Dietitians and the University of Colorado (UCCS) Sport Nutrition Graduate Program.

The Carbohydrate-Insulin Fat Loss Hypothesis

- This is based largely on the "carbohydrate-insulin" hypothesis that a lower carbohydrate intake will expedite lipolysis via diminished insulin activity. On the contrary, a recent meta-analysis concluded that a low carbohydrate diet was no more effective than a low fat diet in terms of weight loss.
- Collectively, this suggests that the effectiveness of a weight loss diet is not dependent on ratios of carbohydrate and fat intake but instead the absolute amount of energy and protein ingested.

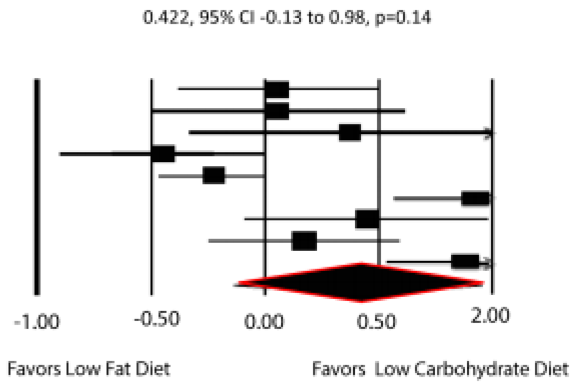


Figure 3: Macronutrient composition and weight loss.

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jay_dietitian

Boaz, M., Raz, O., & Wainstein, J. (2015). Low fat vs. low carbohydrate diet strategies for weight reduction: a meta-analysis. J Obes Weight Loss Ther, 5(273), 2.

Strength and Conditioning Journal
The professional journal of the National Strength and Conditioning Association

Body Recomposition: Can Trained Individuals Build Muscle and Lose Fat at the Same Time?

Christopher Barakat, MS, ATC, CISSN,[1] Jeremy Pearson, MS,[1] Guillermo Escalante, DSc, MBA, ATC, CSCS, CISSN,[2] Bill Campbell, PhD, CSCS, FISSN,[3] and Eduardo O. De Souza, PhD[1]
[1]Department of Health Sciences and Human Performance, The University of Tampa, Tampa, Florida; [2]Department of Kinesiology, California State University, San Bernardino, California; and [3]Performance & Physique Enhancement Laboratory, University of South Florida, Tampa, Florida

研究建議：如何做到同時增肌減脂?

1. 每周至少3次漸增式的阻力訓練
2. 適切地調整訓練：追蹤進步的速率、留意運動表現及恢復
3. 攝取每公斤去脂體重2.6-3.5g蛋白質
4. 蛋白質補充品（乳清/酪蛋白)以增加每日蛋白質攝取量且最大化地刺激肌肉蛋白質合成率
5. 睡眠品質和時間顯著地影響運動表現、恢復和體組成

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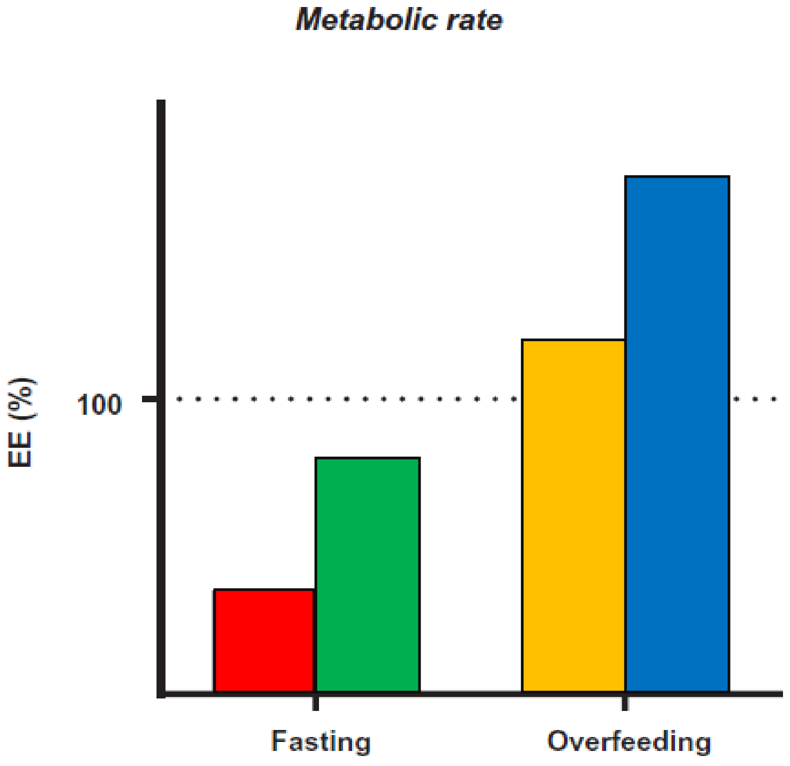
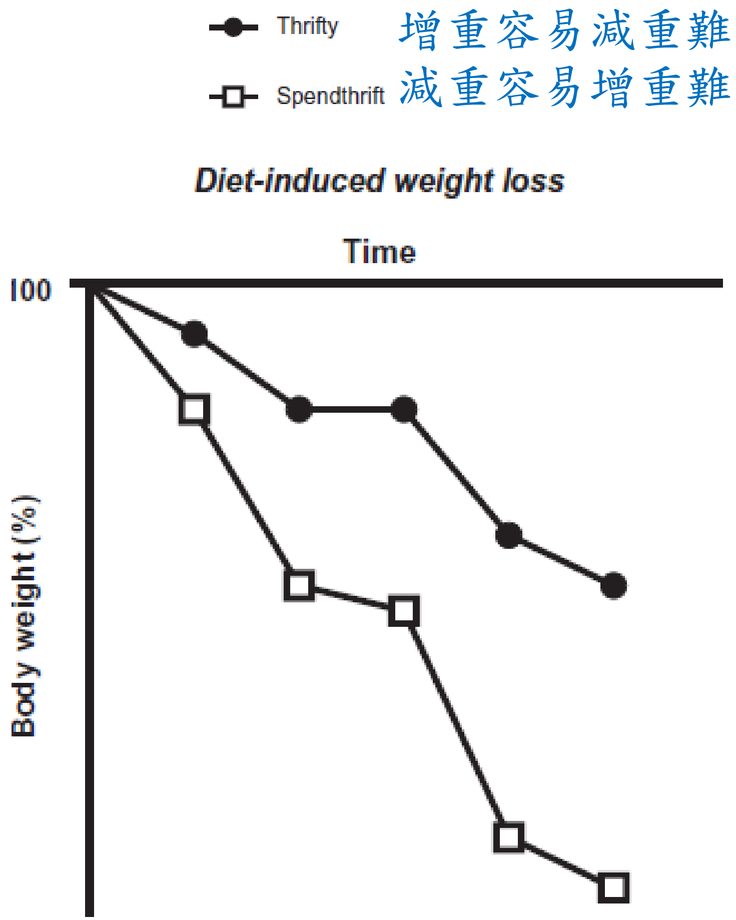
Changes in Body Composition and Neuromuscular Performance Through Preparation, 2 Competitions, and a Recovery Period in an Experienced Female Physique Athlete

Grant M. Tinsley,[1] Eric T. Trexler,[2] Abbie E. Smith-Ryan,[2] Antonio Paoli,[3] Austin J. Graybeal,[1] Bill I. Campbell,[4] and Brad J. Schoenfeld[5]
[1]Department of Kinesiology & Sport Management, Texas Tech University, Lubbock, Texas; [2]Department of Exercise and Sport Science, University of North Carolina, Chapel Hill, North Carolina; [3]Department of Biomedical Sciences, University of Padova, Padova, Italy; [4]College of Education, University of South Florida, Tampa, Florida; and [5]Department of Health Sciences, Lehman College, Bronx, New York

減重速度因人而異





□ 以極端的方法將人分成兩種

1. Thrifty型 (T)
2. Spendthrift型 (S)

□ 短期內給予大量熱量或禁食時的變化

T型-禁食: 能量消耗(EE)減少較多
T型-過度進食: 能量消耗(EE)增加較少
S型-禁食: 能量消耗(EE)減少較少
S型-過度進食: 能量消耗(EE)增加較多

□ 體重變化

1. Thrifty型 (T)減重較慢
2. Spendthrift型 (S)減重較快

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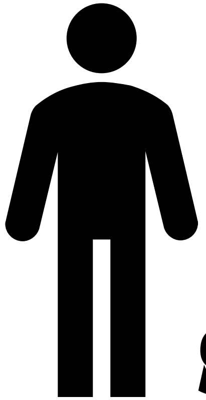
Piaggi, P. (2019). Metabolic determinants of weight gain in humans. Obesity, 27(5), 691-699.

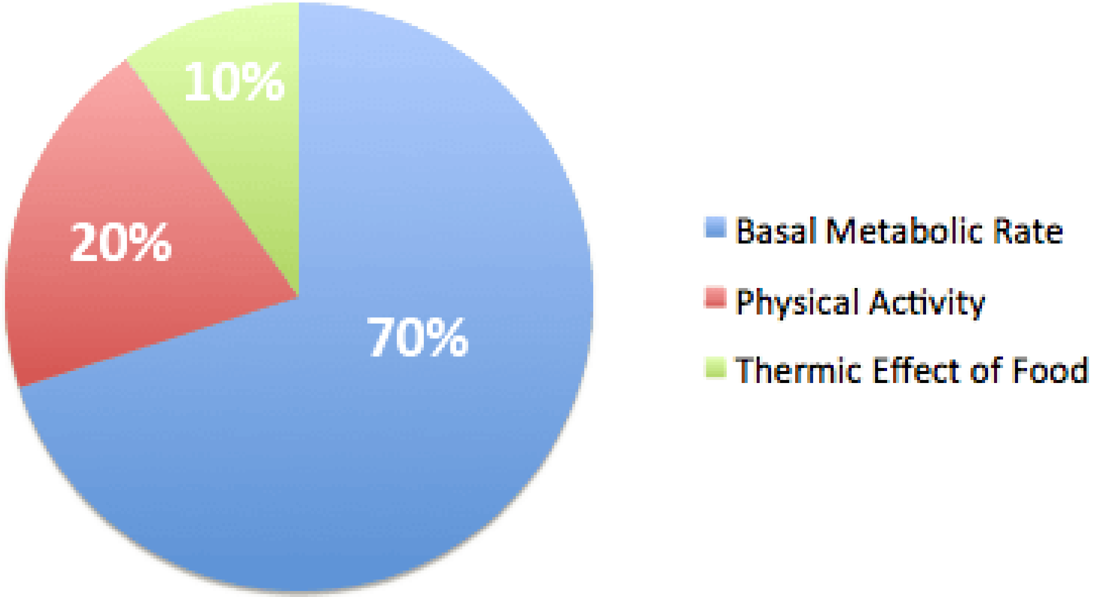
■每日總消耗熱量(TDEE)=
基礎代謝率+攝食生熱效應+**運動消耗熱量+非運動性的熱量消耗**

■能流(Energy Flux)

- 高能流（高能量消耗＋高能量攝取）
- 低能流（低能量消耗＋低能量攝取）



Feed your fitness
Starve your mediocrity



想要維持體重：吃足多動

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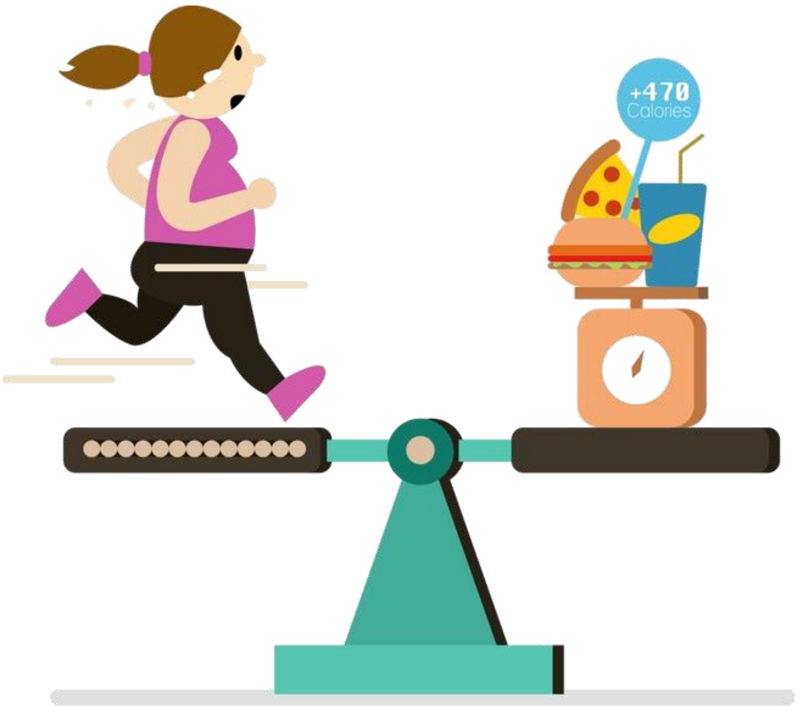
Melby, C. L., Paris, H. L., Sayer, R. D., Bell, C., & Hill, J. O. (2019). Increasing Energy Flux to Maintain Diet-Induced Weight Loss. Nutrients, 11(10), 2533.

今天多吃了XXX，需要跑多久來還債？

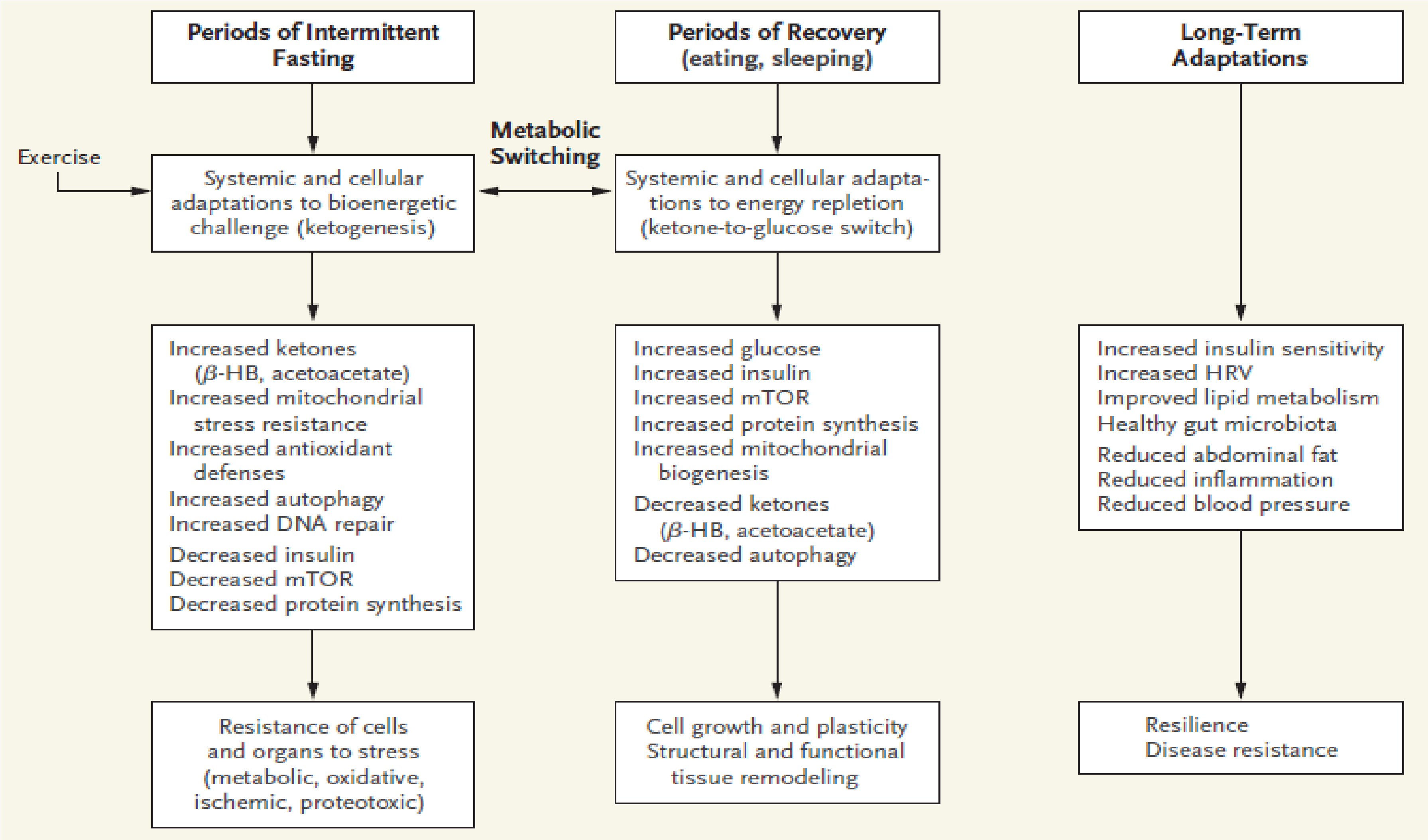


非運動性的熱量消耗(活動量)

1小時消耗	40公斤	50公斤	60公斤	70公斤
慢走(4公里/時)	140	175	210	245
快走(6公里/時)	220	275	330	385

資料來源：國健署

間歇性代謝轉換Intermittent Metabolic Switching
細胞和分子的機制-對抗壓力與疾病



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jay_dietitian

de Cabo, R., & Mattson, M. P. (2019). Effects of Intermittent Fasting on Health, Aging, and Disease. New England Journal of Medicine, 381(26), 2541-2551.

飽食狀態

使用葡萄糖當能量

恢復期(細胞成長)

斷食狀態

肝醣耗盡時，使用
脂肪酸與酮體當能量

汰舊損壞細胞期
(增加身體抗壓力的能力)

規律運動強化
斷食時的作用

重覆斷食→復食→斷食→復食

長期下來，身體會產生適應，以面對接踵而來的挑戰，道理如同經由運動挑戰後，身體變得更加強壯。

間歇性斷食作用

增加抗氧化能力
增加DNA修復
增加蛋白質品質控管
增加粒線體生合成
增加自噬作用
下調發炎反應
移除氧化的受損蛋白和粒線體
回收未受損的物質
暫時減少蛋白質合成率(保存能量)

飲食過量並久坐的人
沒有此些作用

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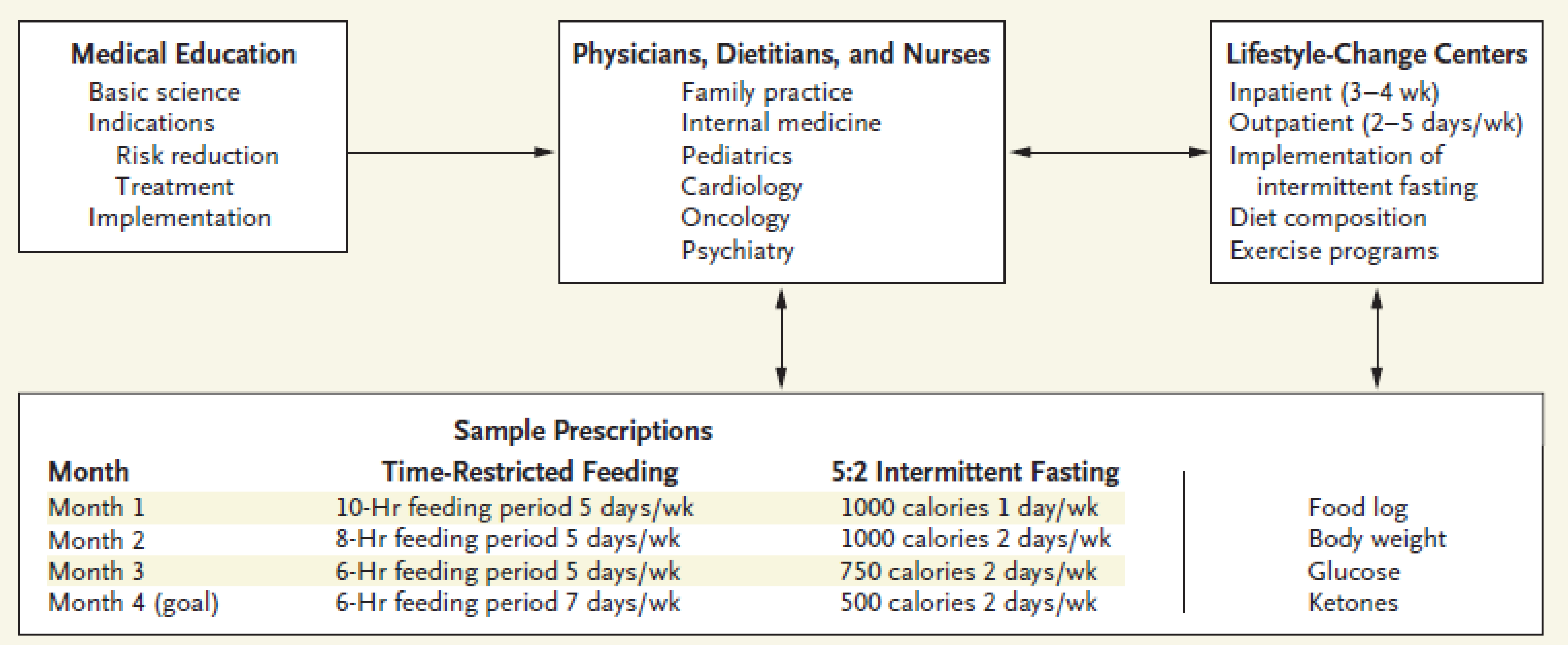
將間歇性斷食納入衛生保健：實踐和生活方式



執行須經由醫師的指示，並時常回診，執行期間須觀察並評估體重、血糖、酮體。

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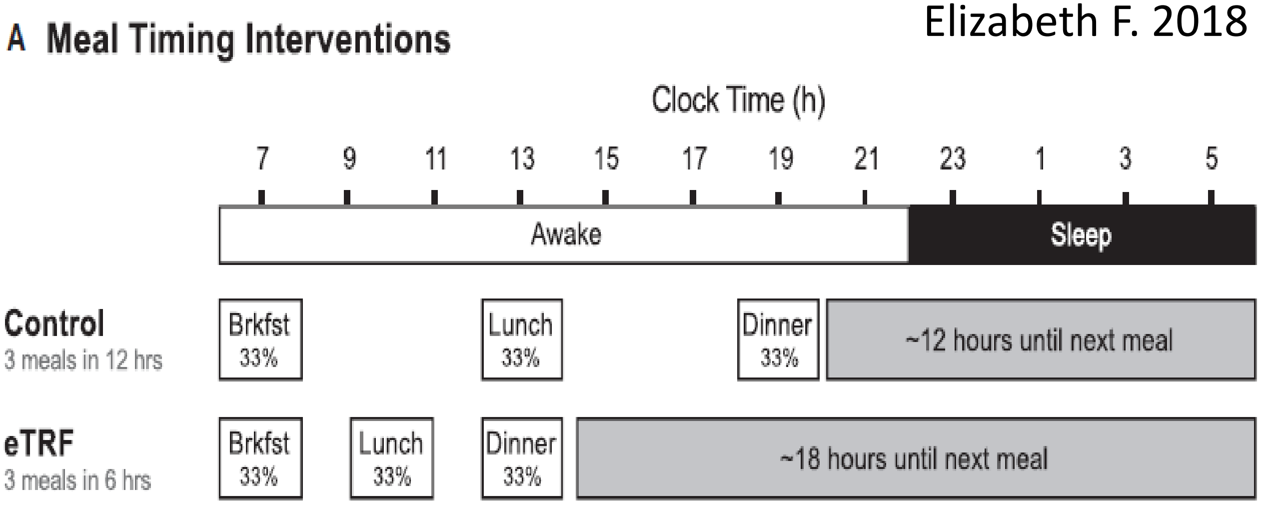
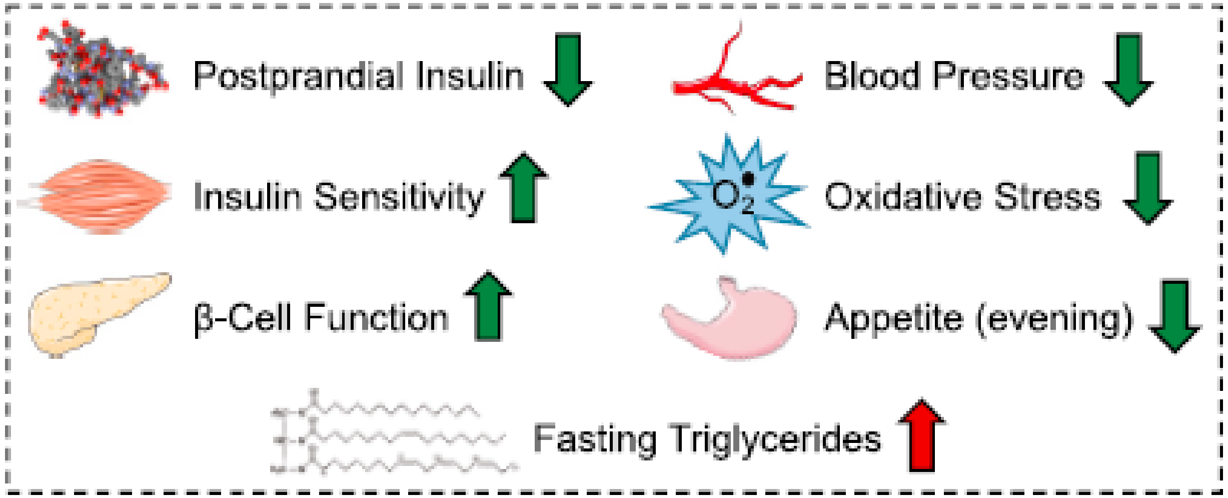
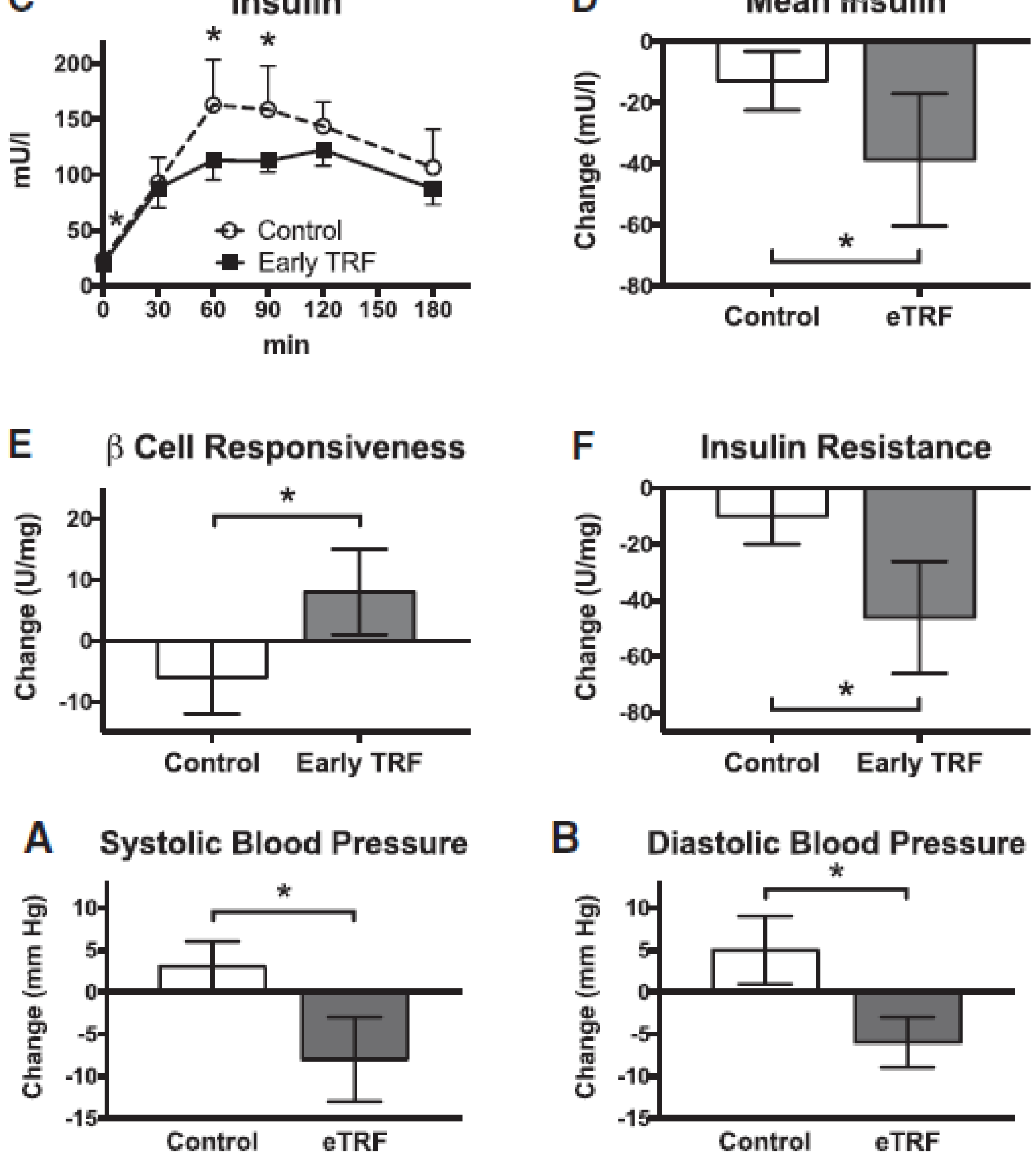
限制時間在早上進食(六小時)

Elizabeth F. 2018







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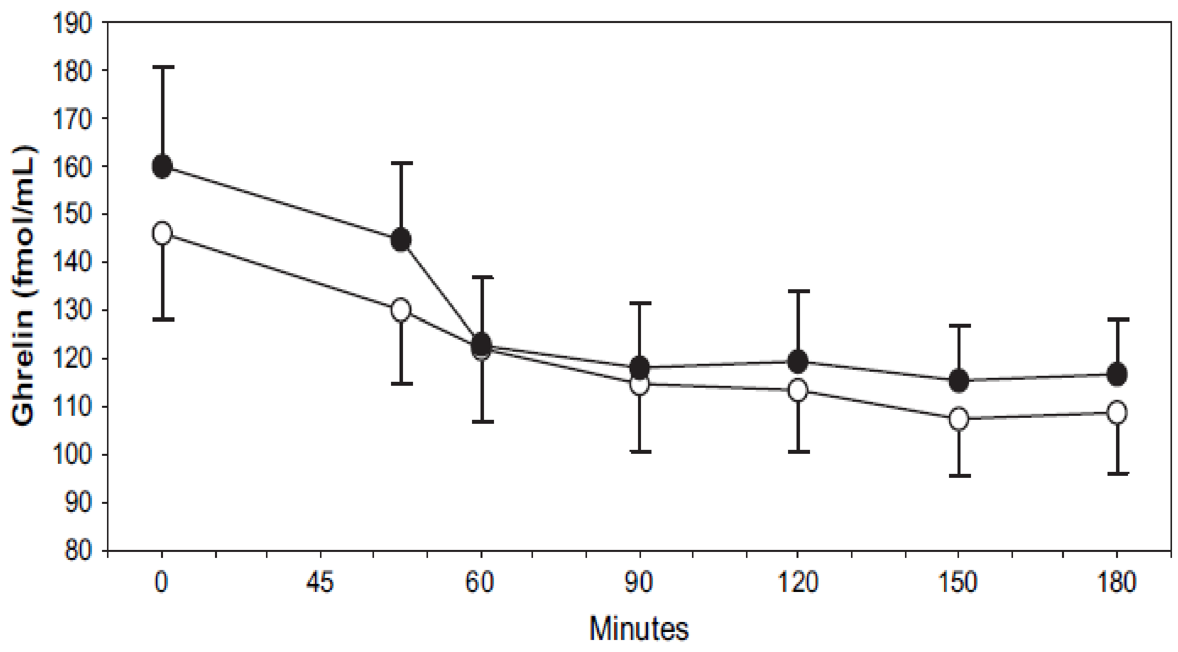
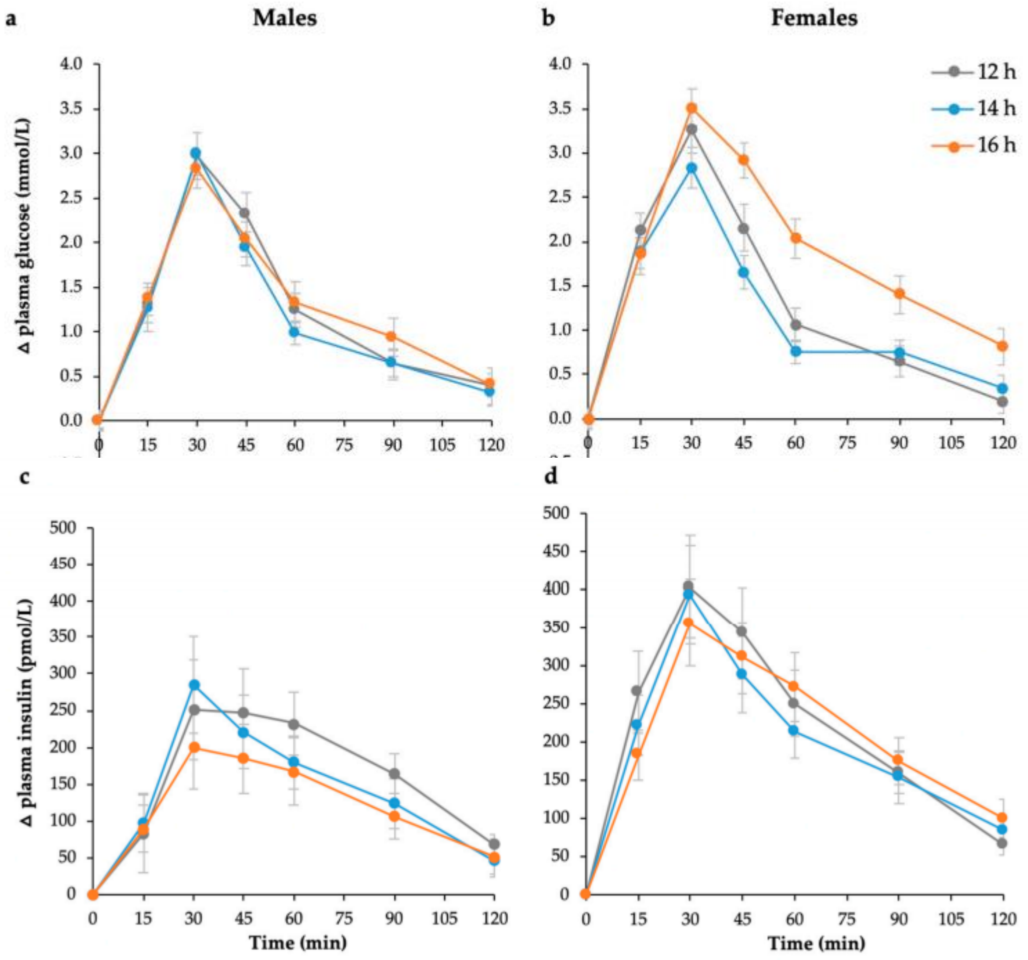
斷食時間越長→飢餓感越高

	12F	17F
Glucose (mmol/L)	4.9 ± 0.1	4.9 ± 0.1
Insulin (pmol/L)	29.4 ± 3.0	24.0 ± 1.8
Ghrelin (fmol/mL)	146 ± 18	160 ± 20*,**
Hunger (VAS)	5.1 ± 0.4	7.0 ± 0.3*,**

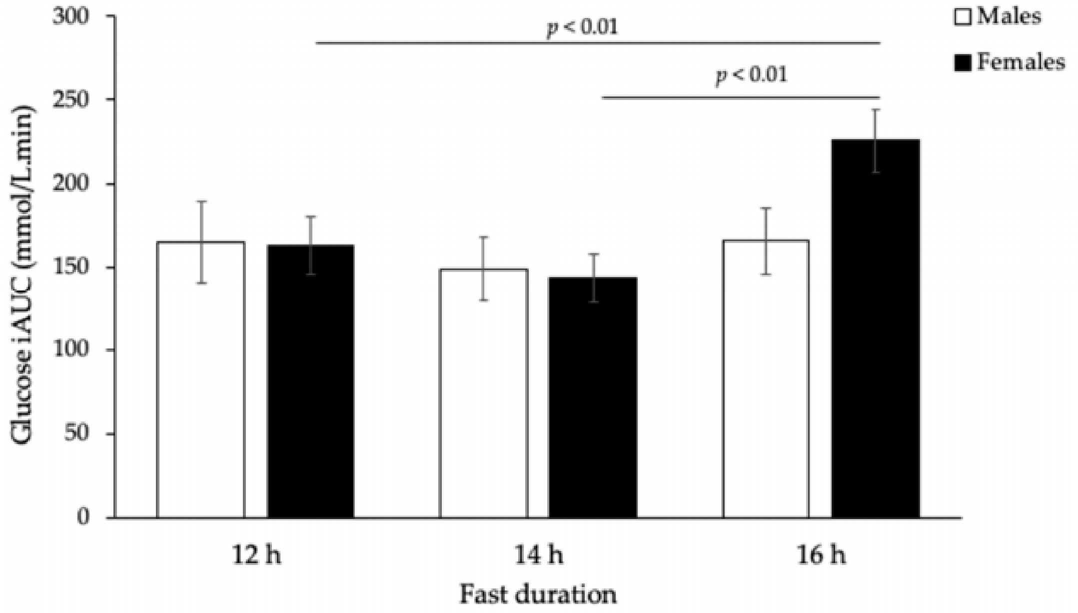


Lucia Briatore, 2006

女性越長時間斷食的副作用 M:12;F12



研究方法：
第一天晚餐19:00食用了研究人員提供的標準晚餐（男性為654kcal,女性為505kcal.55%來自於碳水化合物,15%來自於蛋白質,30%來自於脂肪)
接著斷食12,14,16小時
第2天早上吃標準早餐(392kcal,75 g碳水化合物,3 g脂肪,12 g蛋白和3 g纖維)



S Atkinson, F., A Heruc, G., MH Tan, V., Petocz, P., & C Brand-Miller, J. (2020). Extending the Overnight Fast: Sex Differences in Acute Metabolic Responses to Breakfast. *Nutrients*, *12*(8), 2173.

間歇性斷食與每日減少熱量攝取減重效果一樣

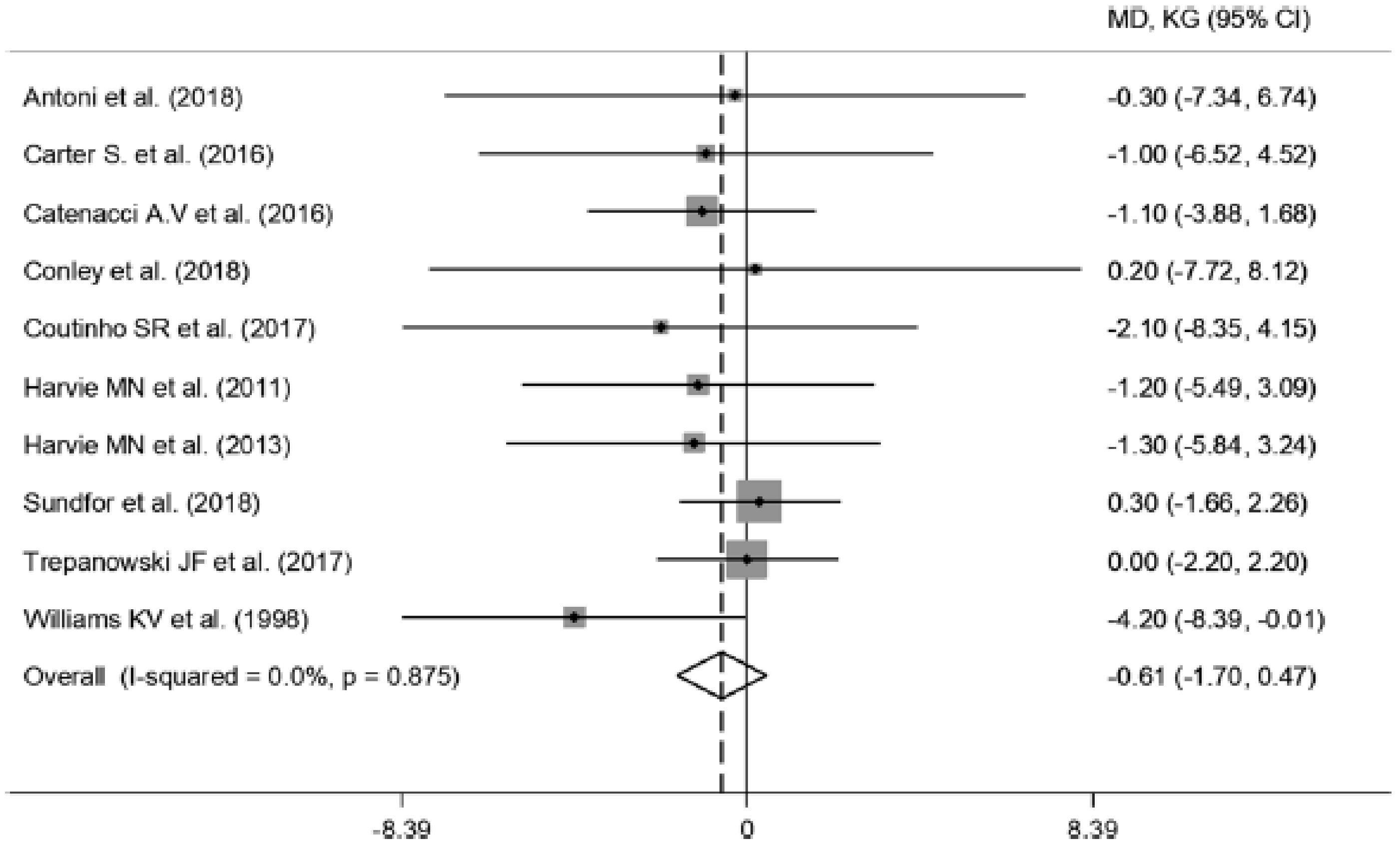


Fig. 2 Meta-analysis of the effects of intermittent energy restriction versus continuous energy restriction on weight loss. MD (mean difference) indicates the mean difference on change from baseline of the IER vs. the CER arms. The plotted points are the mean differences and the horizontal error bars represent the 95% confidence intervals. The grey areas are proportional to the weight of each study in the random-effects meta-analysis. The vertical dashed line represents the pooled point estimate of the mean difference. The solid black line indicates the null hypothesis (MD = 0)

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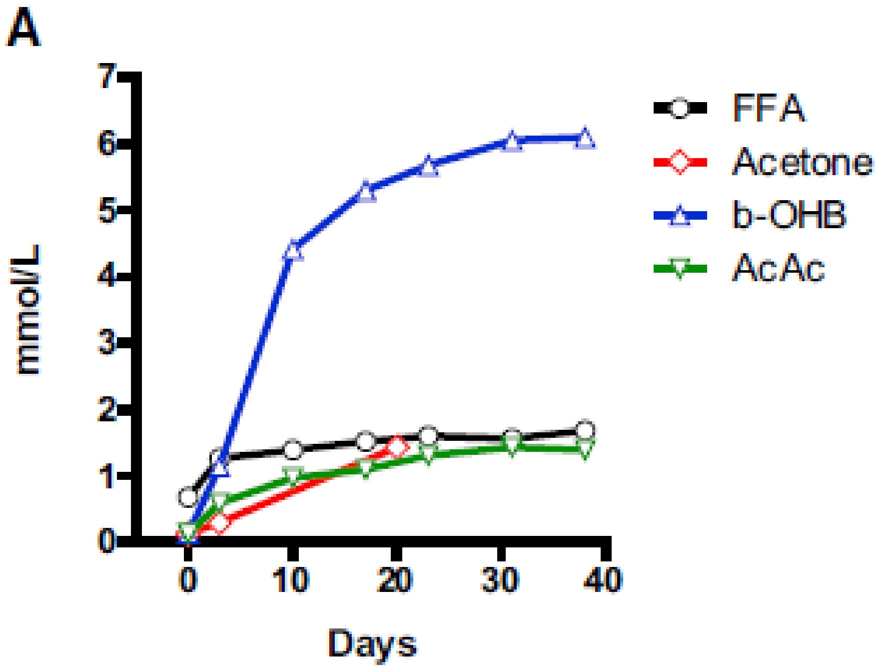
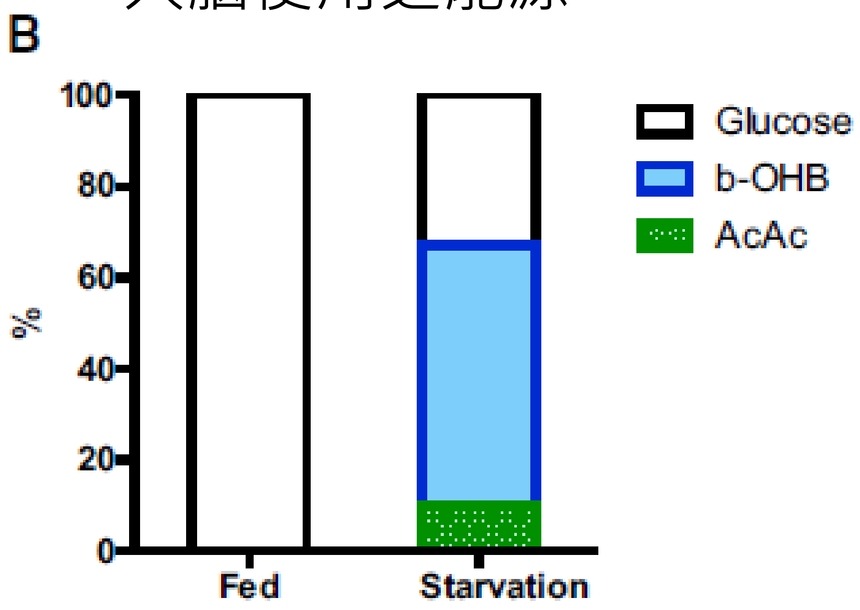
Iolanda Cioffi, 2018

長時間斷食時的身體反應



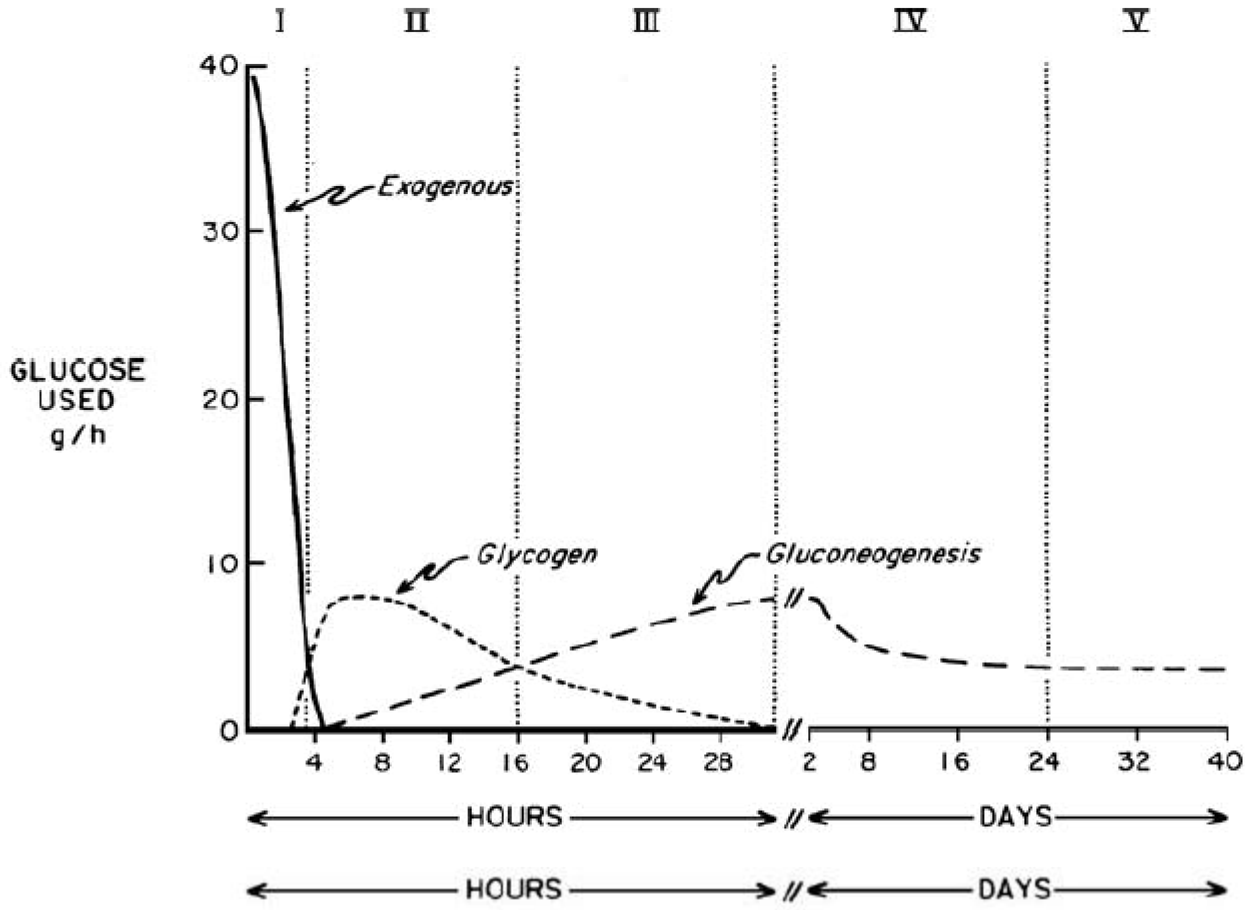
大腦使用之能源



膳食脂質之代謝	
長時間禁食之影響	1. 會導致肝臟中過量脂肪酸的氧化，導致形成大量的乙醯輔酶A， 2. 若超過進入檸檬酸循環的能力，乙醯輔酶A會成對結合形成酮體， 3. 例如：乙醯乙酸 (acetoacetate) 和β-羥基丁酸 (β-hydroxybutyrate)，並釋放到循環中。 4. 在飢餓或長時間低碳水化合物攝取期間，酮體會成為大腦葡萄糖的重要能源替代物。

「國人膳食營養素參考攝取量」第八版

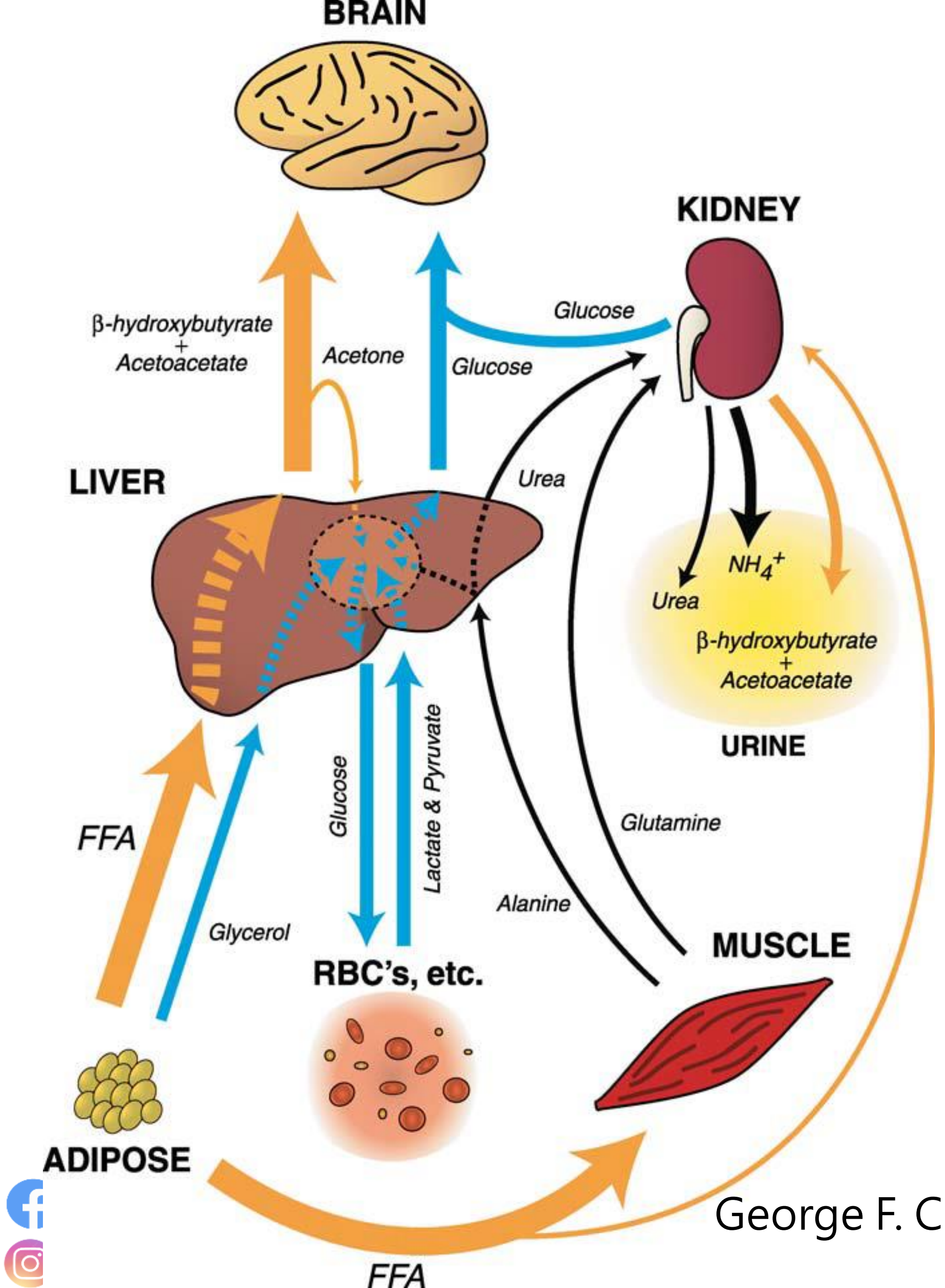
George F. Cahill, Jr. 2006



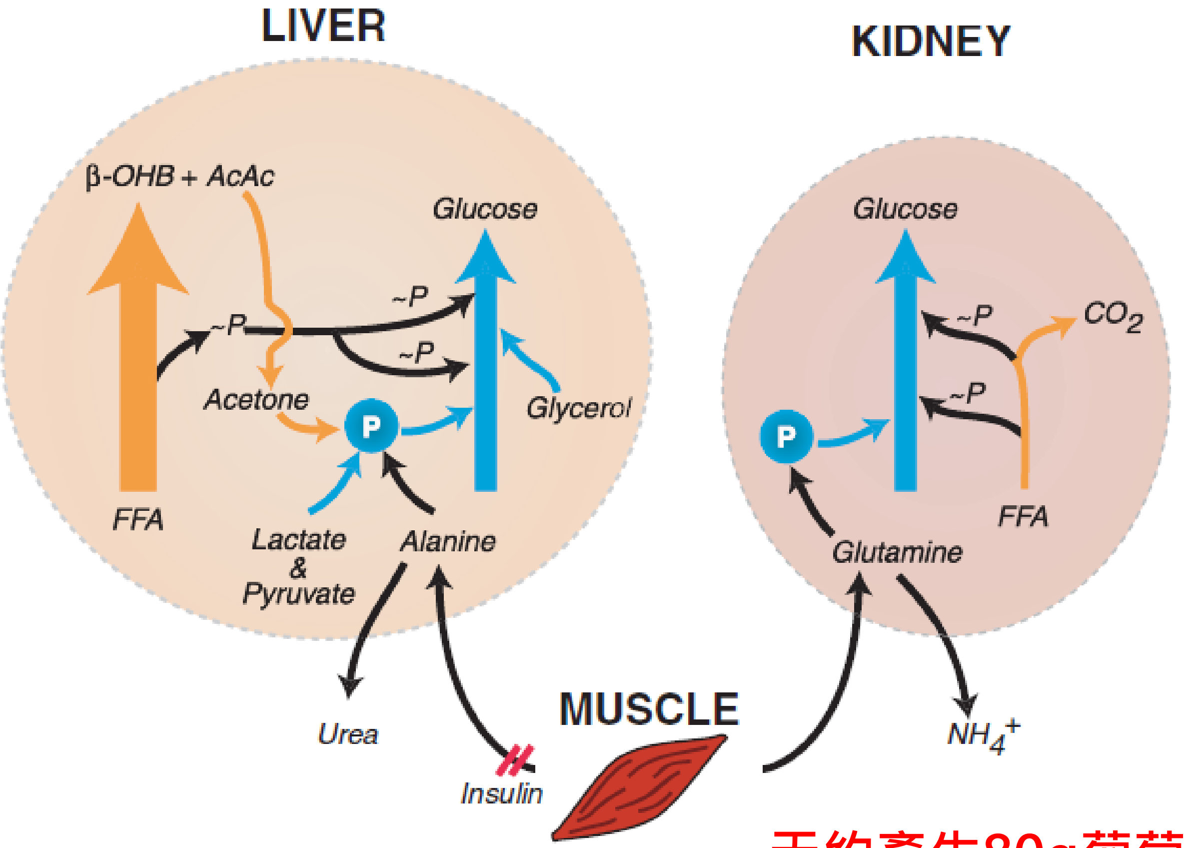
	(I)	(II)	(III)	(IV)	(V)
ORIGIN OF BLOOD GLUCOSE :	Exogenous	Glycogen Hepatic gluconeogenesis	Hepatic gluconeogenesis Glycogen	Gluconeogenesis, hepatic and renal	Gluconeogenesis, hepatic and renal
TISSUES USING GLUCOSE :	All	All except liver. Muscle and adipose tissue at diminished rates	All except liver. Muscle and adipose tissue at rates intermediate between II and IV	Brain, rbcs, renal medulla. Small amount by muscle	Brain at a diminished rate, rbcs, renal medulla
MAJOR FUEL OF BRAIN :	Glucose	Glucose	Glucose	Glucose, ketone bodies	Ketone bodies, glucose

Figure 1 The five metabolic stages between the postabsorptive state and the near-steady

Glucogenesis - Starvation



George F. Cahill, Jr. 2006

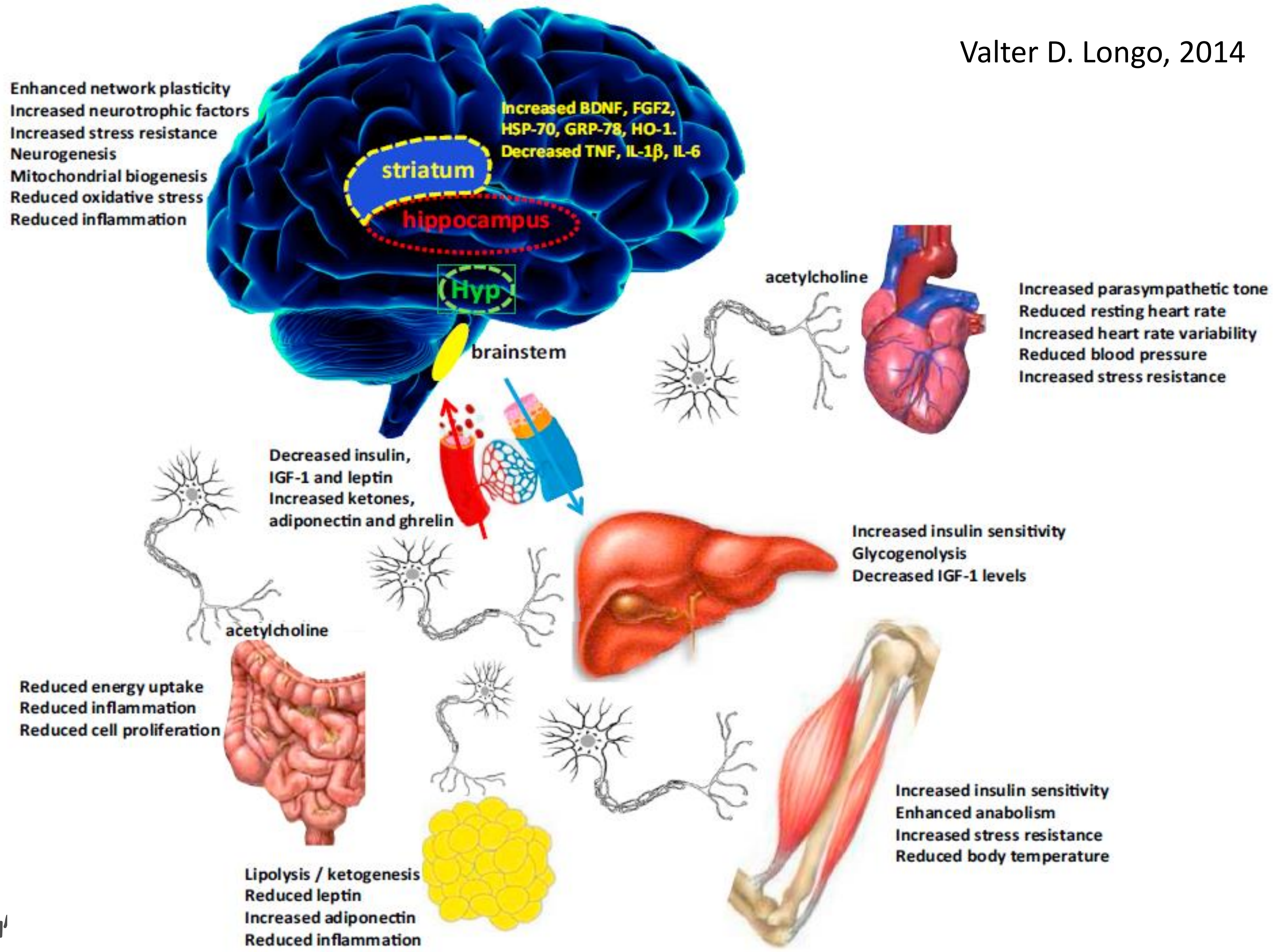


一天約產生80g葡萄糖

10g	Ketone Bodies
35-40g	Lactate、pyruvate
20g	Glycerol
15-20g	Amino Acid

George F. Cahill, Jr. 2006

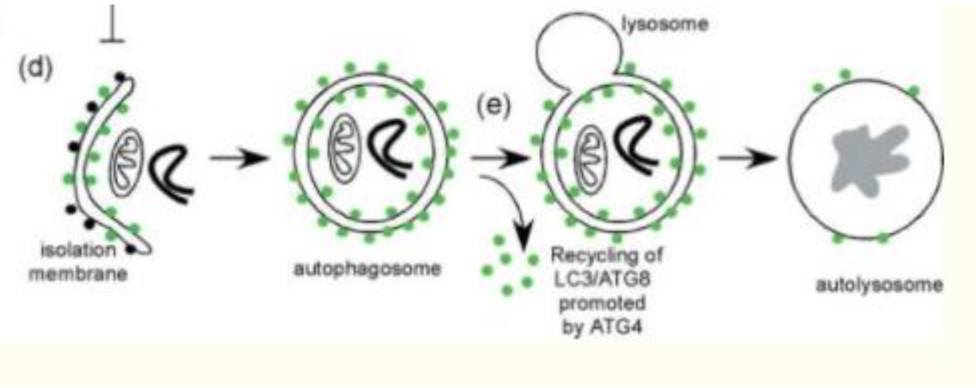
Valter D. Longo, 2014



Autophagy

- Autophagy is a self-degradative process that is important for balancing sources of energy at critical times in development and in response to nutrient stress. Autophagy also plays a housekeeping role in removing misfolded or aggregated proteins, clearing damaged organelles, such as mitochondria, endoplasmic reticulum and peroxisomes, as well as eliminating intracellular pathogens.

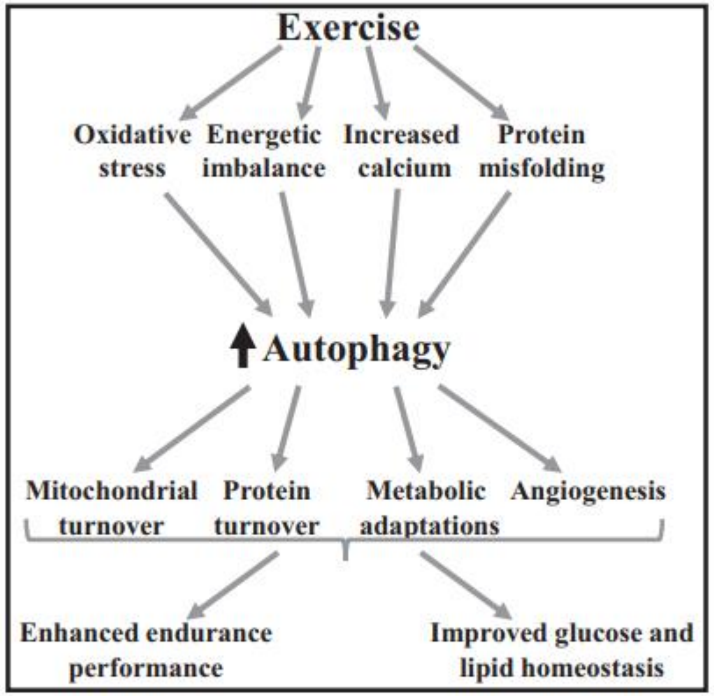
Survival Mechanism

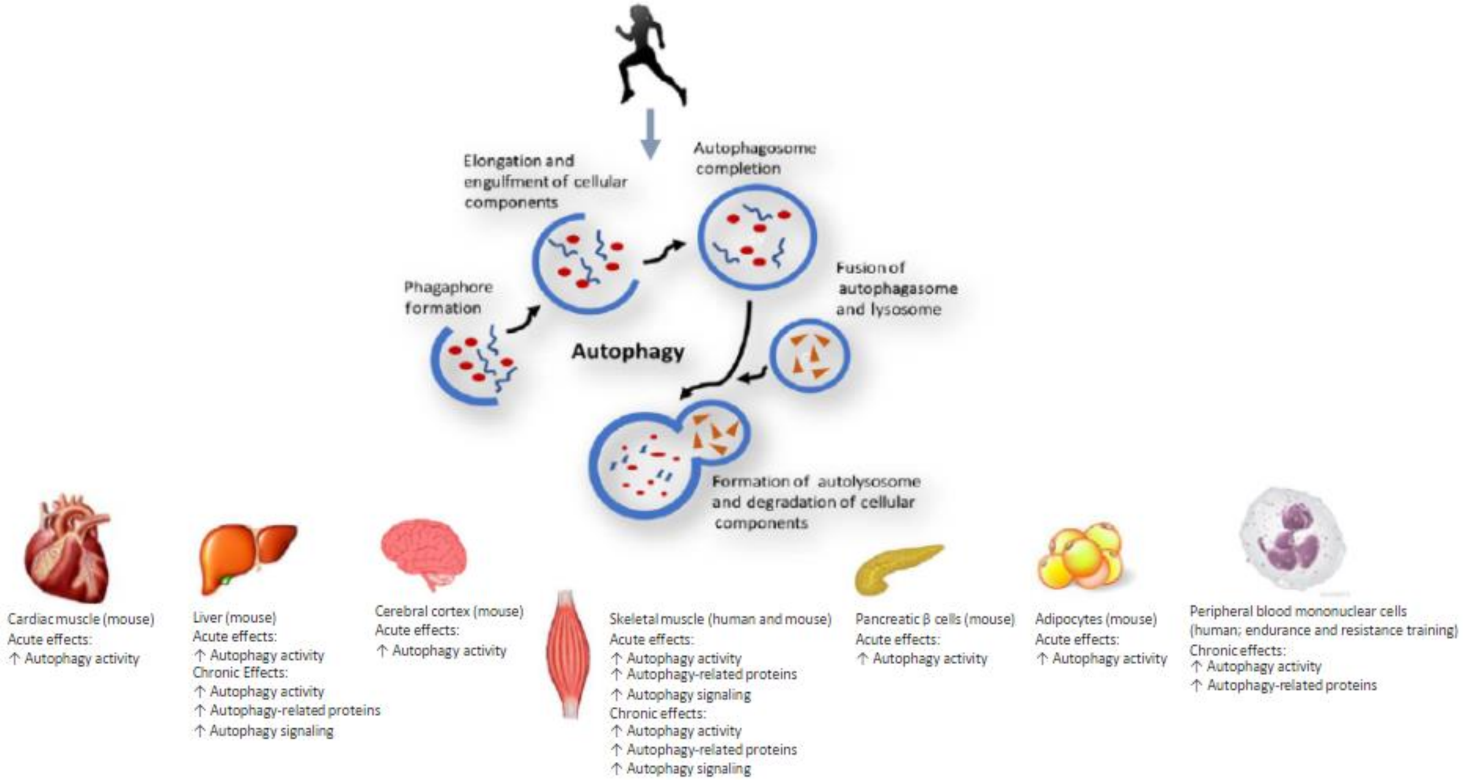


Glick, D., Barth, S., & Macleod, K. F. (2010). Autophagy: cellular and molecular mechanisms. *The Journal of pathology*, *221*(1), 3-12.

運動也能誘發細胞自噬作用

Exercise and CR result in a concomitant downregulation of TORC1 activity and upregulation of autophagy in a number of tissues. Moreover, exercise-induced TORC1 and autophagy signaling share common pathways with that of CR.





Escobar, K. A., Cole, N. H., Mermier, C. M., & VanDusseldorp, T. A. (2019). Autophagy and aging: Maintaining the proteome through exercise and caloric restriction. *Aging cell*, *18*(1), e12876.

Vainshtein, A., & Hood, D. A. (2016). The regulation of autophagy during exercise in skeletal muscle. *Journal of Applied Physiology*, *120*(6), 664-673.

Does the Ketogenic Diet Works for Bodybuilders?

- The KD is an effective fat loss tool, on par with other calorie-restricted diets. Participants frequently report large reductions in hunger, and caloric intake tends to decrease spontaneously.
- Resistance training performance does not seem to be hampered by KD in trained populations.
- The KD seems unsuitable for off-season bulking.

Table 1
Effects upon initiation of the ketogenic diet

Period	Intramuscular glycogen stores	Total body water	Body weight	Side effects	Hunger
When starting the diet	Decreased by 20–54% after 1–6 weeks	Decreased by ~1–5 kg after 1–8 weeks	Decreased, *highly variable*	Increased, *highly variable*	Decreased, *highly variable*

Changes are dependent on level of calorie and carbohydrate restriction.

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Tzur, A., & Roberts, B. M. (2020). The Ketogenic Diet for Bodybuilders and Physique Athletes. Strength & Conditioning Journal, 42(5), 108-115.

生酮飲食與健美運動員

■高蛋白生酮飲食

■生酮飲食用在減脂期較為合適
目前研究不建議用在增肌期

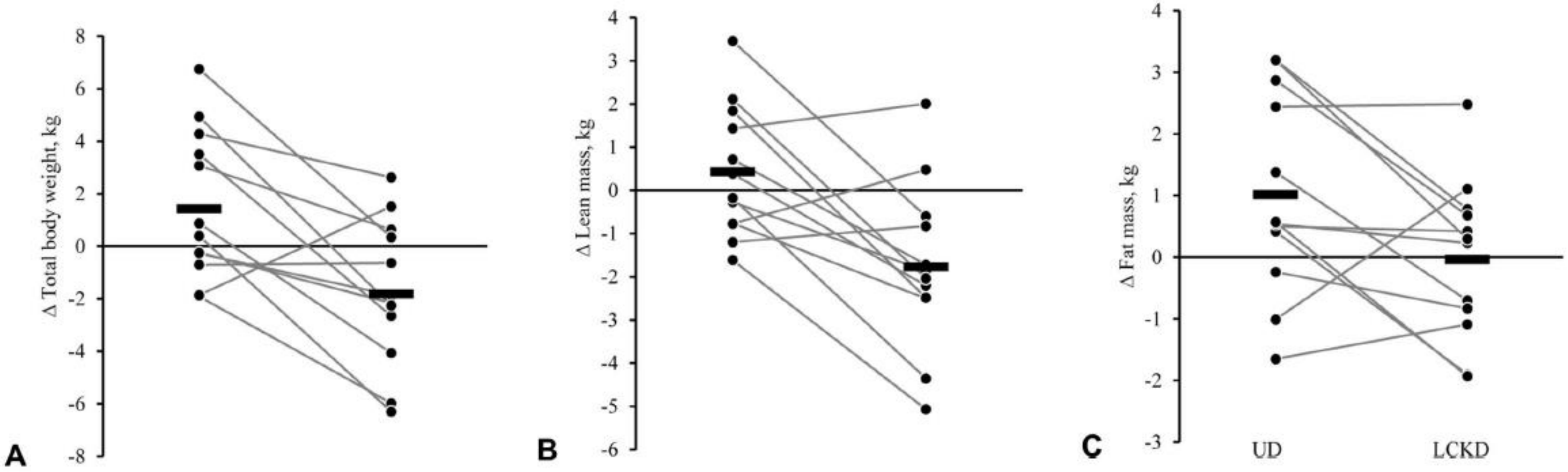
○ 優點
1. 飢餓感下降
2. 非刻意但會減少熱量攝取

✕ 缺點
1. 肌肉肝醣、水分減少
2. 肌肉圍度(外觀)下降
3. 執行初期容易產生副作用

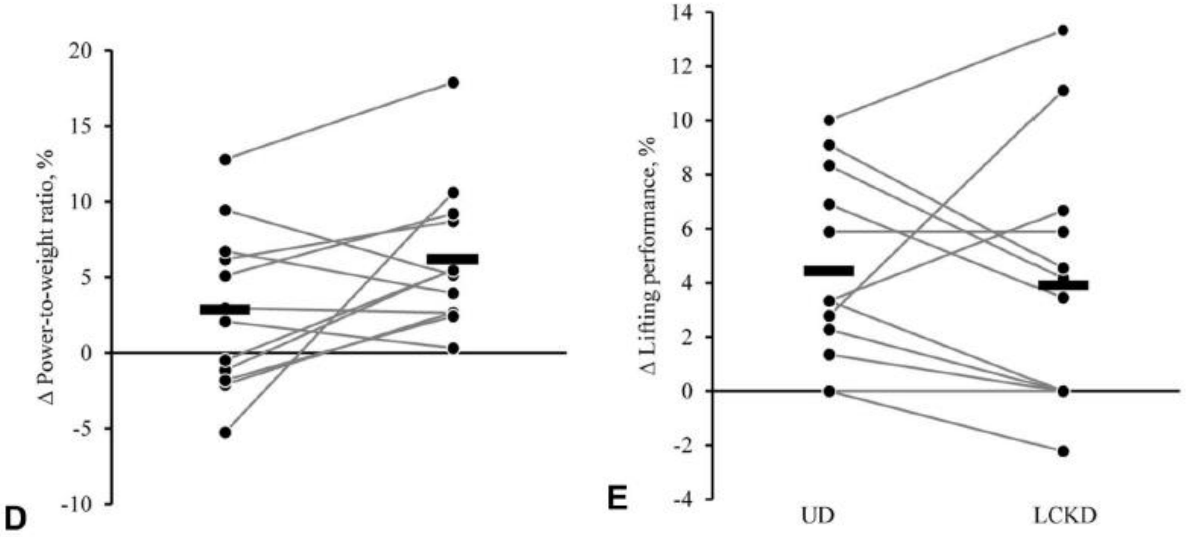
2020 NSCA. The Ketogenic Diet for Bodybuilders and Physique Athletes. Strength and Conditioning Journal

	肌肉肝醣	身體總水重	體重	副作用	飢餓感
執行**初期**	6周內，減少約20-54%	8周內減少 1-5公斤	減少	增加	減少

生酮飲食與舉重、健力運動員



受試者：5女7男
隨機交叉試驗



體重變化：10位使用生酮飲食後，體重減少較多
瘦體重變化：9位使用生酮飲食後，瘦體重減少較多
脂肪重變化：9位使用生酮飲食後，脂肪重減少較多
運動表現變化：8位使用生酮飲食後，表現較差
運動表現變化（體重校正）：8位使用生酮飲食後，表現較佳

Greene, D. A., Varley, B. J., Hartwig, T. B., Chapman, P., & Rigney, M. (2018). A low-carbohydrate ketogenic diet reduces body mass without compromising performance in powerlifting and olympic weightlifting athletes. The Journal of Strength & Conditioning Research, 32(12), 3373-3382.

Does the Ketogenic Diet Works for Bodybuilders?

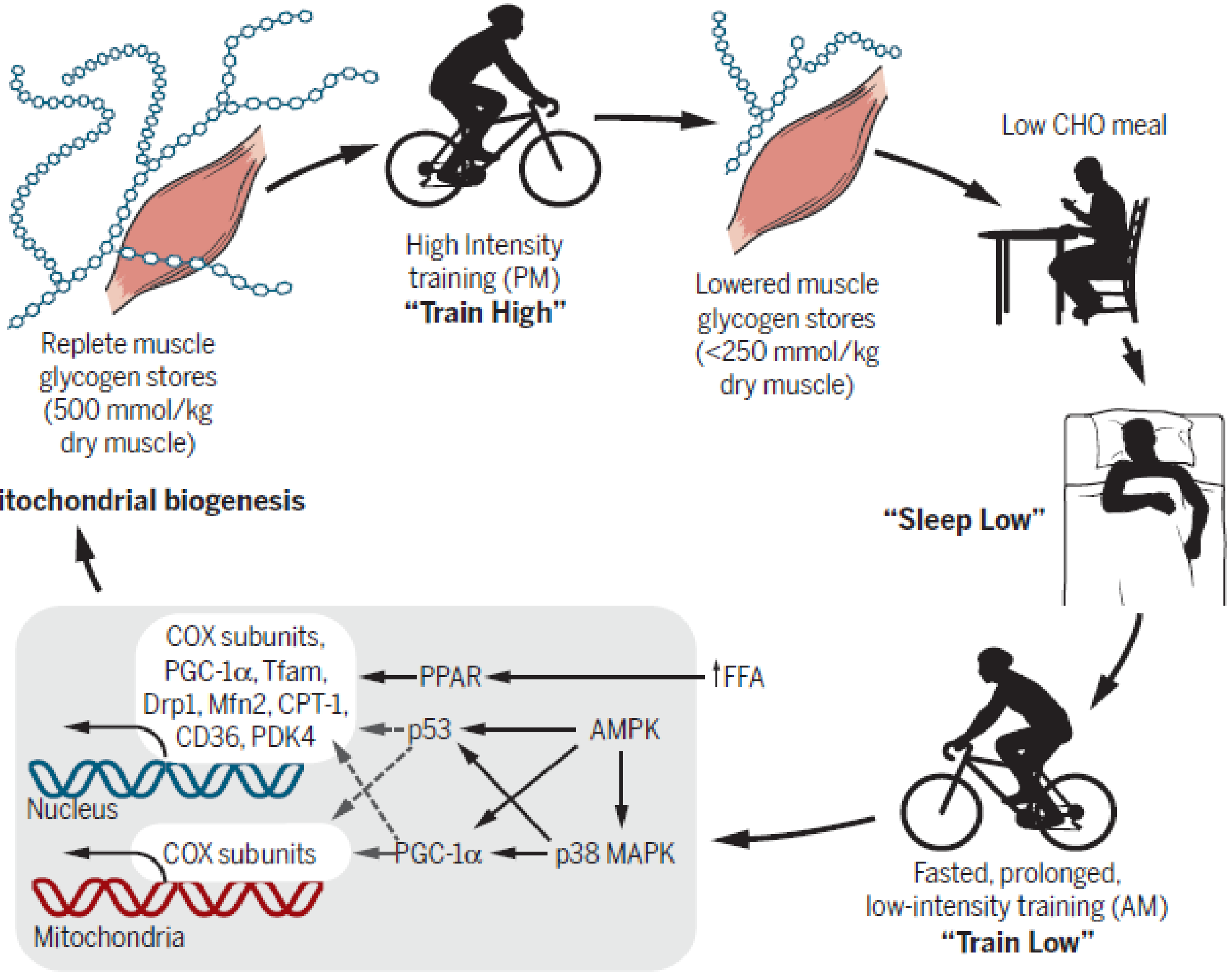
During early stages of contest preparation, when the competitor has time to adjust and adapt to the diet.

For competitors who struggle with adherence due to hunger issues.

If athletes experience few side effects and enjoy the diet.

During off-season bulking. The hunger-reducing effects of the diet and the inability to increase lean mass are potential negatives. Yet, individuals vary, and some may not experience these effects. Personal experimentation is warranted.

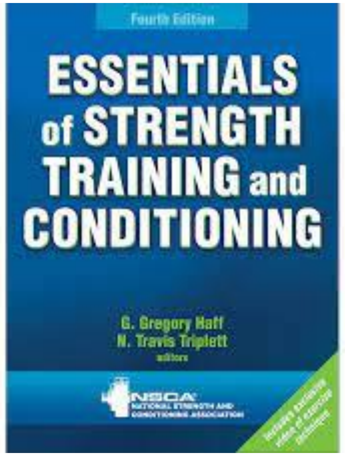
飲食法1：平常訓練
高訓低睡 Train high sleep low



NSCA

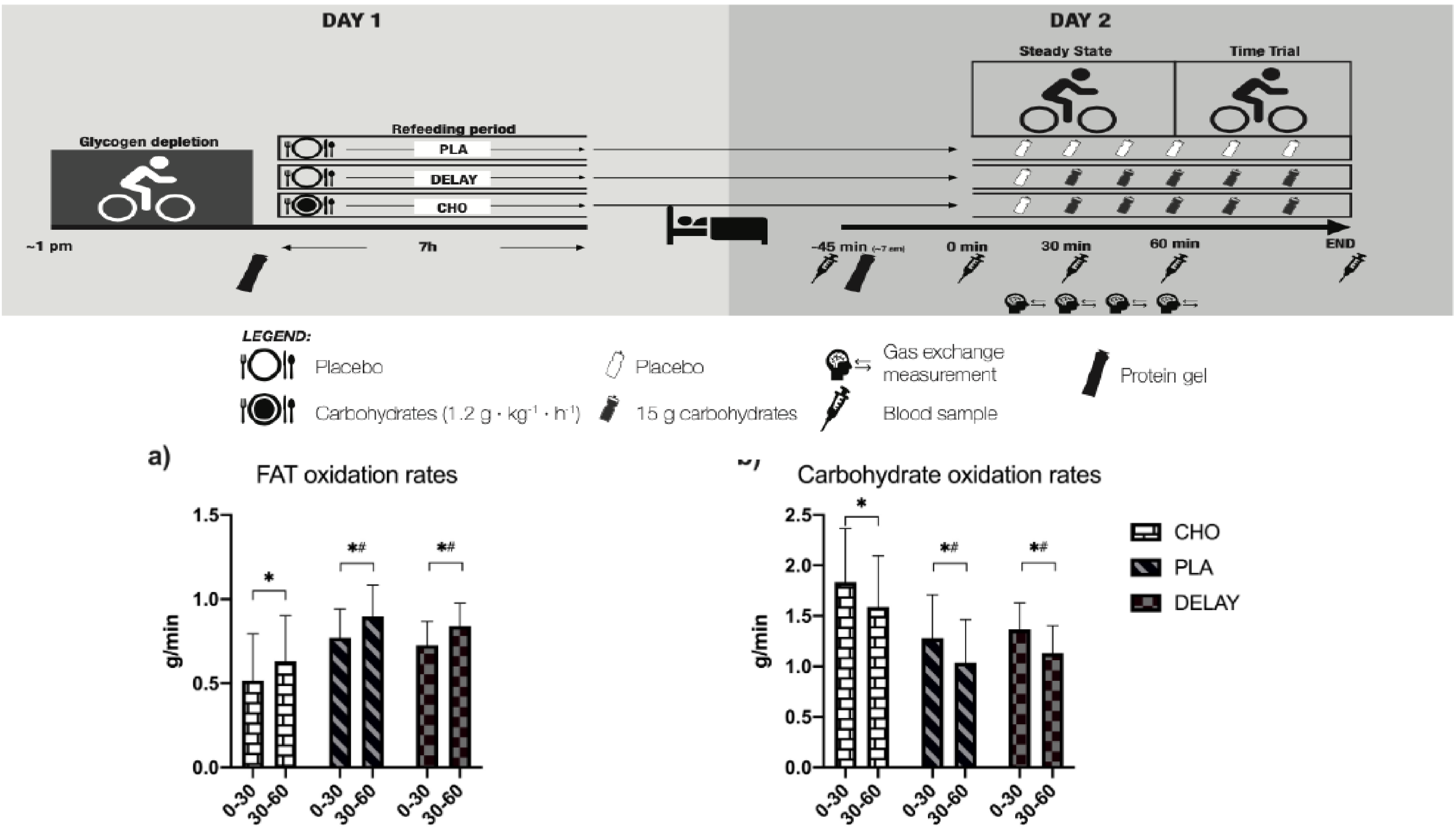
訓練後立即進食

碳水：蛋白質= 3 – 4：1



Burke, L. M., & Hawley, J. A. (2018). Swifter, higher, stronger: What's on the menu?. Science, 362(6416), 781-787.

肝糖濃度低時，運動中攝取醣類仍不影響能量的使用



Podlogar, T., Free, B., & Wallis, G. A. (2020). High rates of fat oxidation are maintained after the sleep low approach despite delayed carbohydrate feeding during exercise. European Journal of Sport Science, (just-accepted), 1-29.

飲食法2：運動員平時訓練適用碳水循環飲食法

✓ **一天練兩餐（休息時間 <8小時）**

此時第一個訓練結束應立即進食碳水以最大化回補肝醣

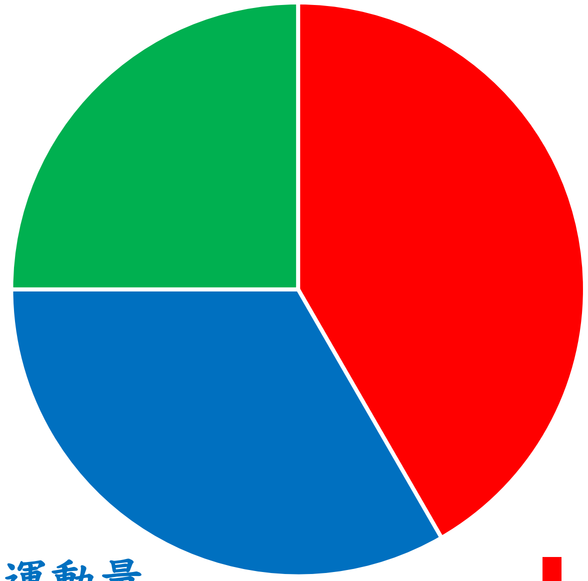
研究建議第一個訓練後4小時內應每小時攝取每公斤體重約1克的碳水，可以是液體類的或是富含碳水的小點心、糖果（以中高GI為主並可加入低GI一起）

✓ **當胃口不好或能量不夠時**

可添加**蛋白質**（20-25g）一起攝取，能增加肝醣回補同時也能增加蛋白質合成率

■ **中等運動量**

每公斤體重5-7 g

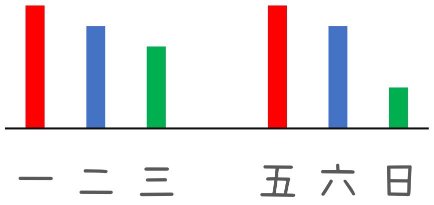


■ **極高等運動量**

每公斤體重8-12 g

■ **高等運動量**

每公斤體重6-10 g



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Reference: Burke, L. M., van Loon, L. J., & Hawley, J. A. (2017). Postexercise muscle glycogen resynthesis in humans. Journal of Applied Physiology, 122(5), 1055-1067.

熱量相同時，吃運動補充品和麥當勞有差異嗎?

Table 1　Fast Food Feeding

Fast Food	Energy (kJ)	Fat (g)	Cho (g)	Pro (g)	Qty	Sodium (mg)
0 hr						
Hotcakes	1464	9	60	8	1	590
Hashbrown	628	9	15	1	1	310
Orange Juice (small)	628	0	34	2	1	0
Total	2720	18	109	11		900
2 hr						
Hamburger	1046	9	31	12	1	480
Coke (medium)	837	0	54	0	1	45
Fries (small)	962	11	29	3	1	160
Total	2845	20	114	15		685
4 hr total	5565	38	223	26		1585

Table 2　Sport Supplement Feeding

Sport Supplement	Energy (kJ)	Fat (g)	Cho (g)	Pro (g)	Qty	Sodium (mg)
0 hr						
Gatorade (20 oz)	544	0	34	0	1	270
Kit's Organic PB	837	11	25	6	2	95
Cliff Shot Bloks (1 blok)	139	0	8	0	4	17
Total	2775	22	116	12		527
2 hr						
Cytomax (1 scoop, 10 oz)	377	0	22	0	2	120
Power Bar Recovery PBCC	1088	10	30	12	1	180
Power Bar Energy Chews	837	0	46	3	1	30
Total	2678	10	120	15		450
4 hr total	5453	32	236	27		977

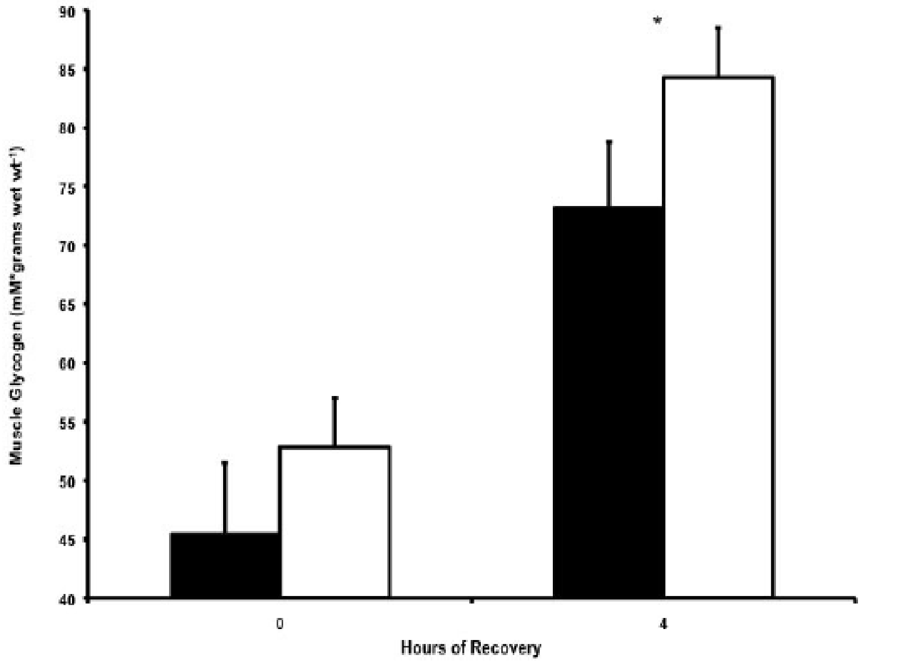

Figure 1 — Muscle glycogen concentration during recovery. Solid square = SS, Open square = FF *$p < .05$ ($n = 11$) main effect for time vs 0 hr. Values are mean ± *SEM*.

Cramer, M. J., Dumke, C. L., Hailes, W. S., Cuddy, J. S., & Ruby, B. C. (2015). Postexercise glycogen recovery and exercise performance is not significantly different between fast food and sport supplements. International journal of sport nutrition and exercise metabolism, 25(5), 448-455.

結語

- 飲食需求應針對不同族群、不同運動項目、不同目標給予不同的運動營養處方
- 每個人應找到適合自己的飲食模式，並定期做健康檢查。

A healthy outside starts from the inside

Robert Urich