



Sports Nutrition



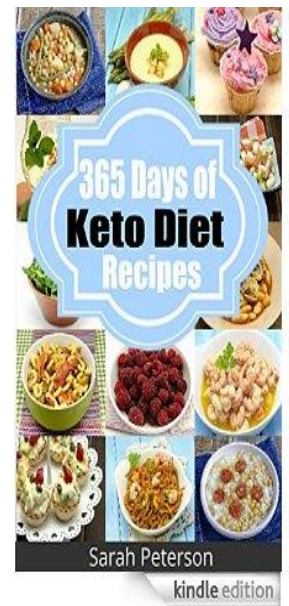
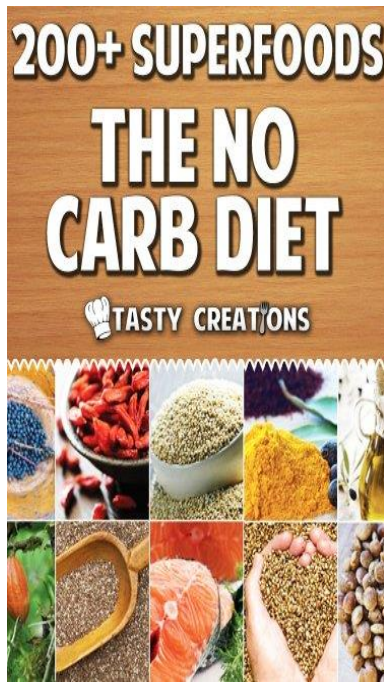
Iñigo San Millán, PhD
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Nutrition- The Importance of Carbohydrates in Performance



Carbohydrates Public Enemy #1??

Are they really that bad for you??





Carbohydrates weren't sent 10 years ago by Aliens from Outer Space to Exterminate Humankind !

In fact....Paleo diet was rich in Starchy foods!

Earliest evidence for caries and exploitation of starchy plant foods in Pleistocene hunter-gatherers from Morocco

Louise T. Humphrey^{a,1}, Isabelle De Groot^{a,b}, Jacob Morales^{c,d}, Nick Barton^e, Simon Collcutt^f, Christopher Bronk Ramsey^g, and Abdeljalil Bouzouggar^{h,i}

^aDepartment of Earth Sciences, The Natural History Museum, London SW7 5BD, United Kingdom; ^bResearch Centre in Evolutionary Anthropology and Palaeoecology, School of Natural Sciences and Psychology, Liverpool John Moores University, Liverpool L3 3AF, United Kingdom; ^cGrupo Investigación Arqueobiología, Centro de Ciencias Humanas y Sociales, Consejo Superior de Investigaciones Científicas 28037 Madrid, Spain; ^dMcDonald Institute for Archaeological Research, University of Cambridge, Cambridge CB2 3ER, United Kingdom; ^eInstitute of Archaeology, University of Oxford, Oxford OX1 2PG, United Kingdom; ^fOxford Archaeological Associates, Oxford OX4 1LH, United Kingdom; ^gResearch Laboratory for Archaeology and the History of Art, University of Oxford, Oxford OX1 3QY, United Kingdom; ^hInstitut National des Sciences de l'Archéologie et du Patrimoine, Rabat-Instituts, 10 000 Rabat, Morocco; and ⁱDepartment of Human Evolution, Max Planck Institute for Evolutionary Anthropology, D-04103 Leipzig, Germany

94% of the 50 sets of teeth found in a Paleolithic cave in Morocco had Caries and Tooth Decay as a result of starchy foods



Quaternary International

Available online 18 June 2015

In Press, Corrected Proof — Note to users

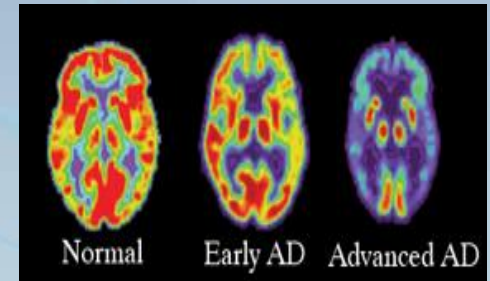
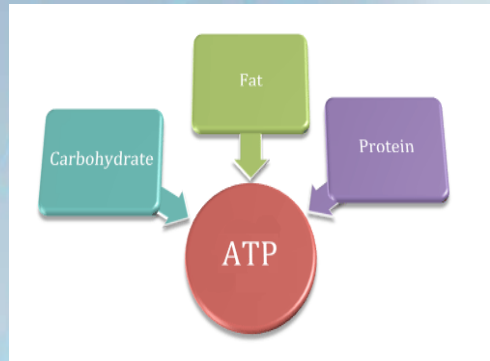
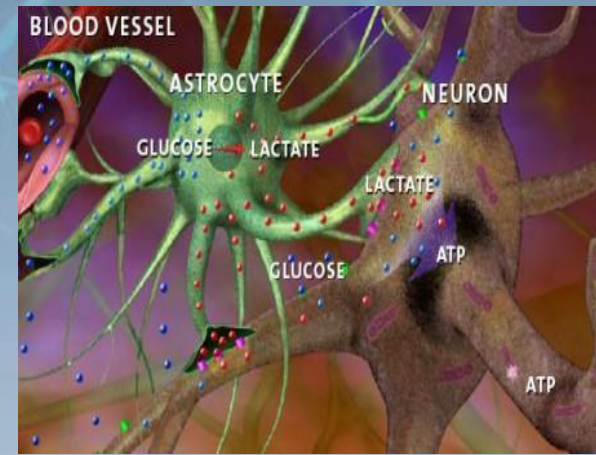
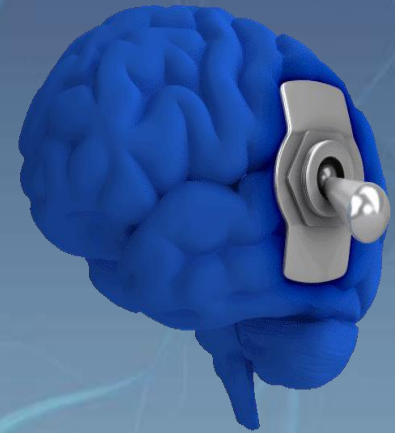


Dental calculus reveals potential respiratory irritants and ingestion of essential plant-based nutrients at Lower Palaeolithic Qesem Cave Israel

Karen Hardy^a, Anita Radini^{b,c}, Stephen Buckley^b, Rachel Sarig^{d,g}, Les Copeland^e, Avi Gopher^f, Ran Barkai^f

Starch granules found in teeth show evidence of plants and starchy foods in Paleolithic diets.



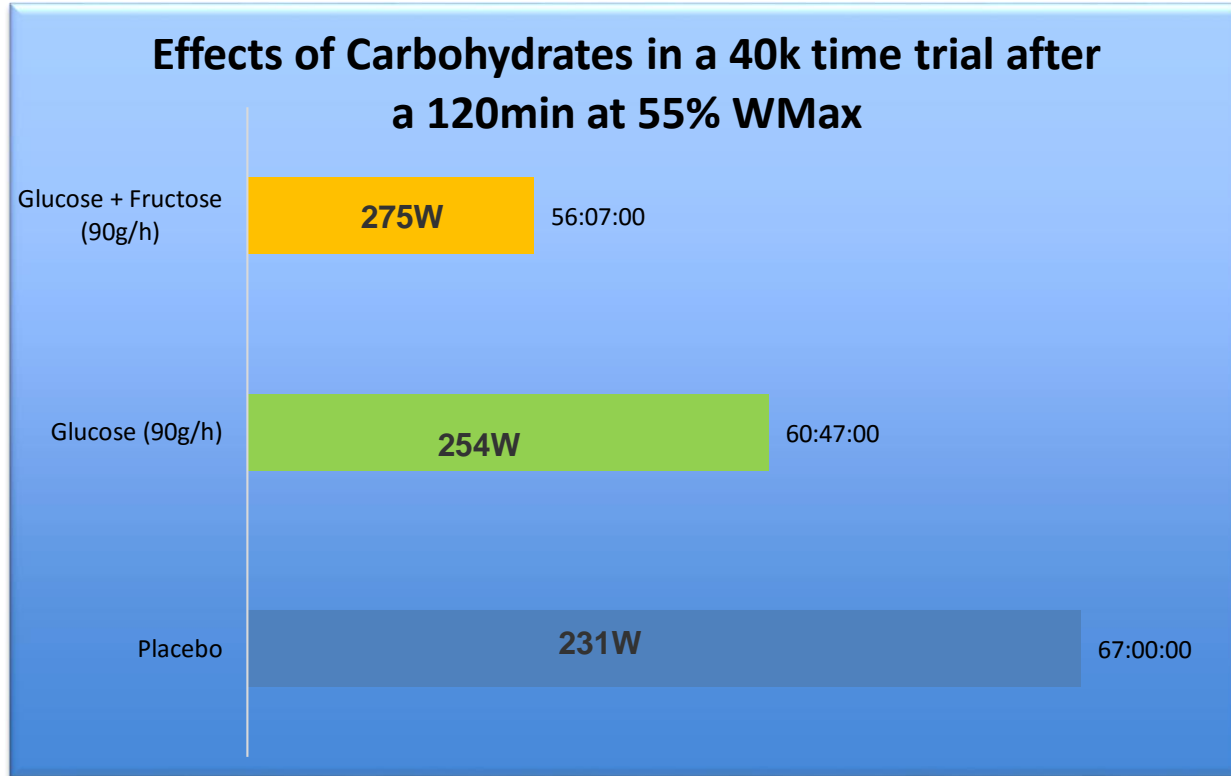


Systematic review: Carbohydrate supplementation on exercise performance or capacity of varying durations

Trent Stellingwerff, Gregory R. Cox. [Appl Physiol Nutr Metab, 2014.](#)



- 61 published studies on Carbohydrate and Performance
- 82% Shows Statistically significant performance benefits (50 studies)
- 18% of studies shows no change compared to placebo
- NO study shows detrimental performance with CHO



Currell and Jeukendrup, 2008



Competition Nutrition Practices of Elite Ultra-Marathon Runners

By Trent Stellingwerff in IJSNEM, June 2015

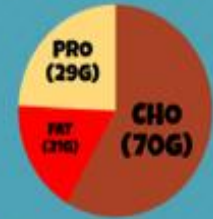
Designed by @YLMSPortScience

3 world-class male ultra-runners
Adam Campbell, Max King & Rob Krar

IN 2014
16 ULTRAMARATHONS WITH A TOTAL OF EIGHT WINS, INCLUDING WINNING THE PRESTIGIOUS WESTERN STATES ENDURANCE RUN 100-MILER



PRE-RACE BREAKFAST



DURING THE 100-MILE RACES

THROUGHOUT THEIR RESPECTIVE 100-MILE RACES, ATHLETES CONSUMED 1162 ± 250G OF CHO (71 ± 20G/H), WITH MINIMAL FAT AND PROTEIN INTAKES



Total caloric intake during the 100-mile
5530 ± 1673 KCAL



ATHLETES ALSO CONSUMED 912 ± 322MG OF CAFFEINE AND 6.9 ± 2.4G OF SODIUM

2 athletes consumed 12.5 and 4.2g of ginger throughout their races



Commercial products accounted for 93 ± 12% of energy intake (sports drinks, gels, candies & commercial colas)

However, one athlete did mention increasing contributions of real food into his fueling plan: "I increasingly use and experiment with real food for races over 12 hours, and I do try and take in a bit of protein and fat. This largely comes down to trying to avoid flavor fatigue." A second athlete noted "at crewed aid stations I also picked up ~1oz. salted chocolate covered almonds. They are an easy way to get some calories and protein in, especially later in the race when gels become less and less appealing."

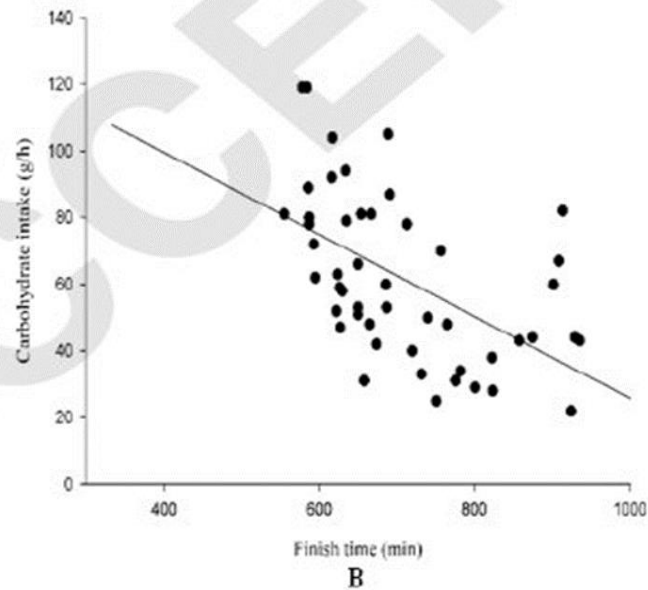
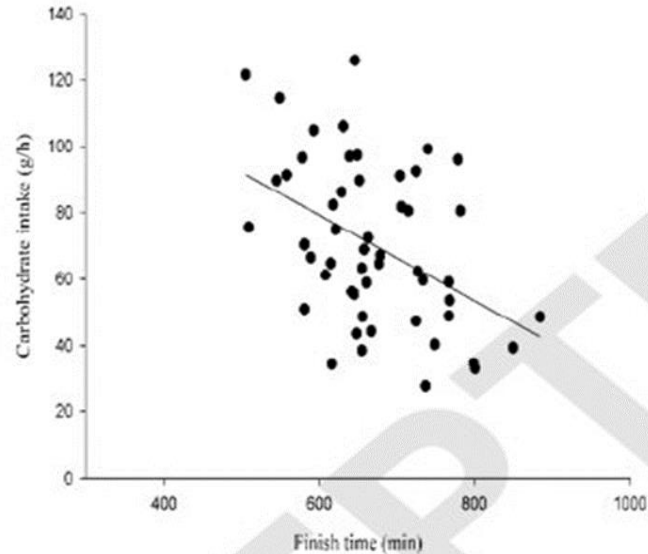


Substrate requirements of elite ultra-marathoner winning the 100-km world-championships

CONCLUSION

All three athletes practice nutrition strategies providing high CHO availability throughout their races. Furthermore, substrate oxidation estimates demonstrated a very CHO vs. fat dominant race performance while winning the World 100km Championships

CHO/h During Ironman



Pfeiffer et al. "Nutritional intake and gastrointestinal problems during competitive endurance events." *Med Sci Sports Exerc* 2012

Kenyan runners have dominated for decades and are the skinniest athletes in the world



Kenyan runners have dominated for decades
and are the skinniest athletes in the world



Kenyan's diets

Energy Intake:

2987Kcal

-Carbohydrates:

76.5%!!

-10.7g/kg/day!!

-Fat: 13.4%

-Protein: 10.1% LOW

-20% SFA, 10% sugars!!

Onywera, V.O. et al. Food and macronutrient intake of elite Kenyan distance runners. Int. J. Sport. Nutr. Exerc. Metab. 14: 709-719, 2004.

Carbohydrates during the Tour de France



- Garmin Riders at TdF**
- Total Energy Intake: 6000-9000 Kcal/day**
- Carbohydrates: 70-75%
 - About 1,000 g/day of CHO
 - 400g simple sugars!!!
 - 4000 kcal/day of CHO
 - 1600 Kcal/day Simple Sugars!
 - 13-14g/kg/day!!

Low CHO Diets and Performance??

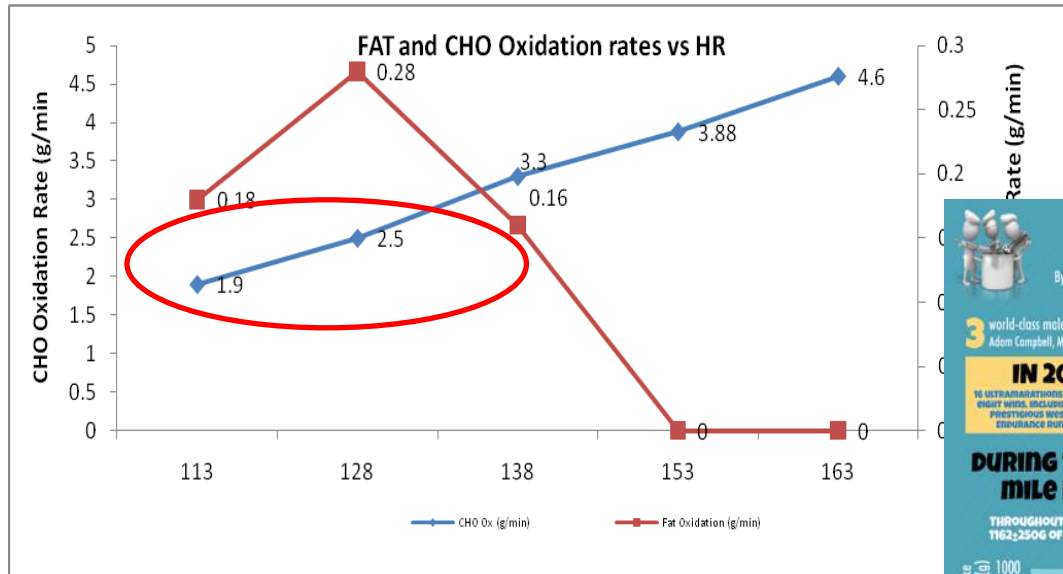


**NO Scientific Study has shown improvements in performance.
In fact, overall, studies show to be detrimental for performance**

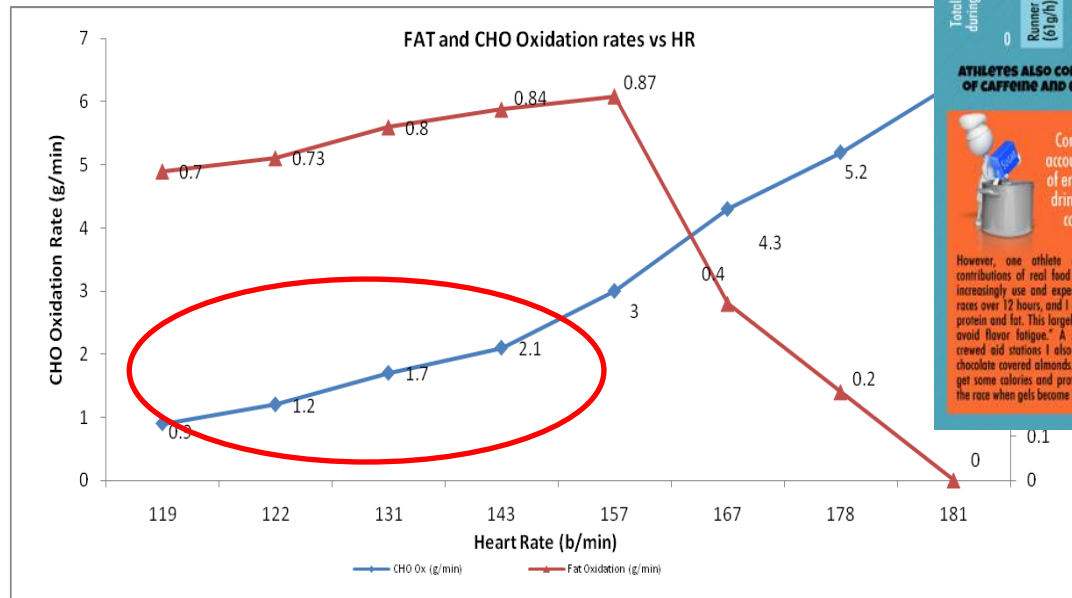
**Can low CHO Diets (Therefore High Fat or High Protein) increase Fat
utilization?**

Yes...HOWEVER, no improvements in performance (normally detrimental).

Recreational Athlete



World Class Athlete



Competition Nutrition Practices of Elite Ultra-Marathon Runners

By Trent Stellingwerff in USNEM, June 2015
Designed by eYUMSportScience

PRE-RACE BREAKFAST

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Total CHO intake during the race (g)

Runner #	CHO Intake (g/h)
#1	61
#2	57
#3	94

Total caloric intake during the 100-mile
5530 ± 1673 KCAL

2 athletes consumed 12.5 and 4.2g of ginger throughout their races

ATHLETES ALSO CONSUMED 912 ± 322MG OF CAFFEINE AND 6.9 ± 2.4G OF SODIUM

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PRE-RACE BREAKFAST

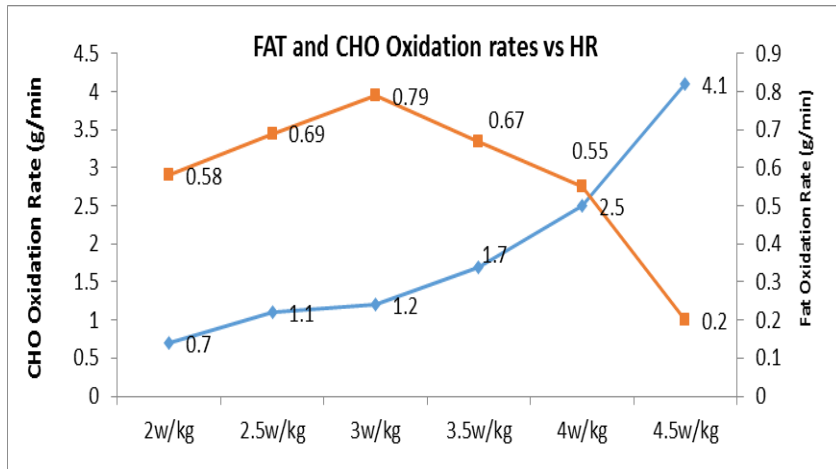
PRO (29G)
CHO (70G)
FAT (29G)

DURING THE 100-MILE RACES

Glucose
Free-fatty acids
Intramuscular triglycerides
Glycogen

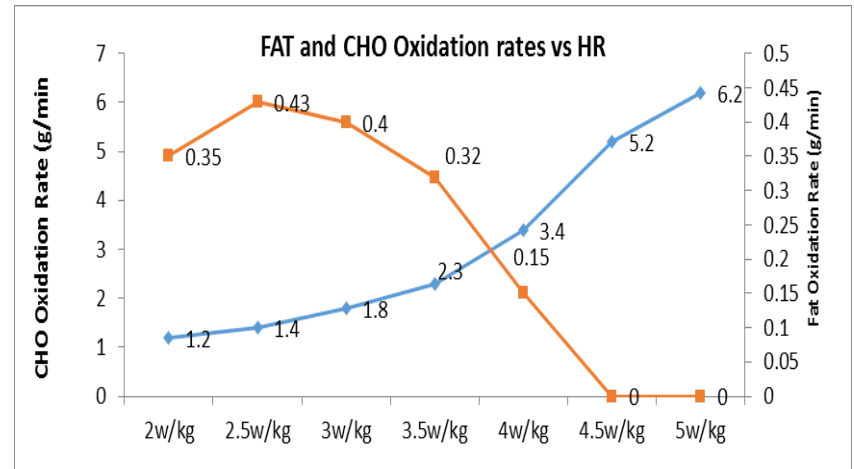
Low CHO Diets Increase Fat Utilization and Performance??

LOW CHO Diet



Max Power Output= 315W
(4.5w/kg)

Restored Normal CHO Diet

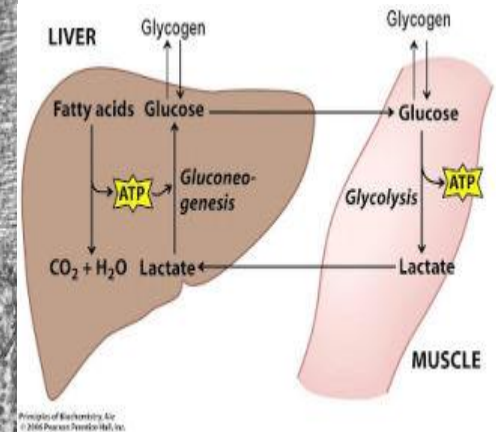
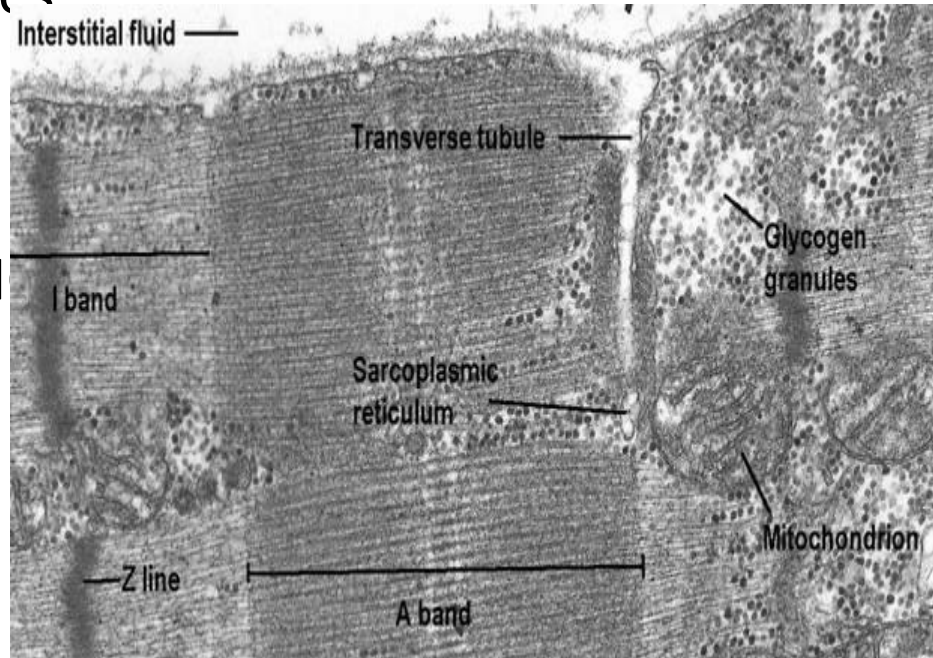


Max Power Output= 350W
(5w/kg)

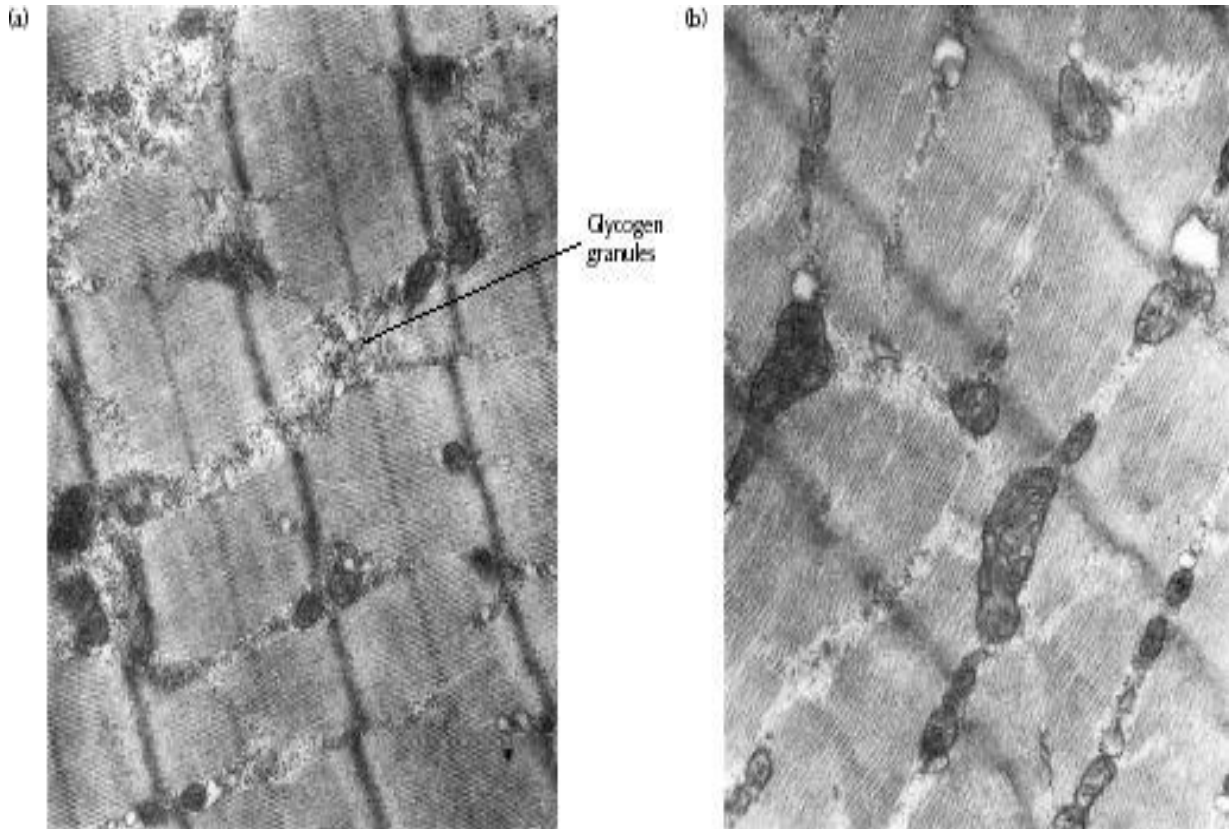


- Glycogen and Performance
 - What is Glycogen??

- Glycogen is Carbohydrate store in the body
- 85% in Muscles
- 15% in Liver
- We can only store ~1lb Of CH

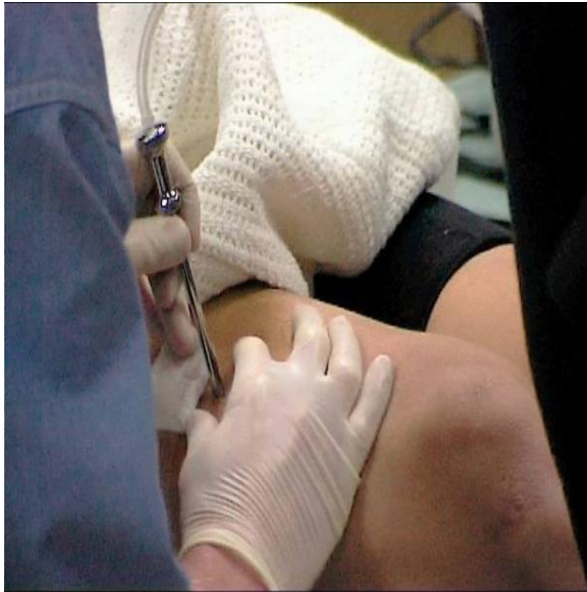


Can we measure Glycogen?

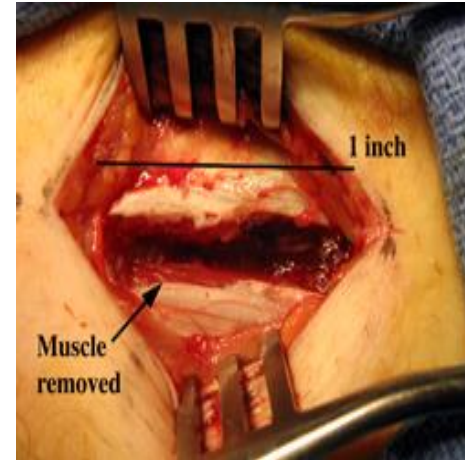


Absolutely!!

Muscle Biopsy

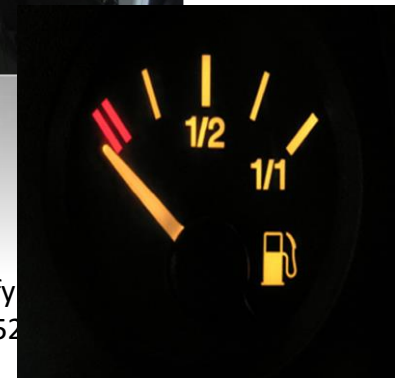
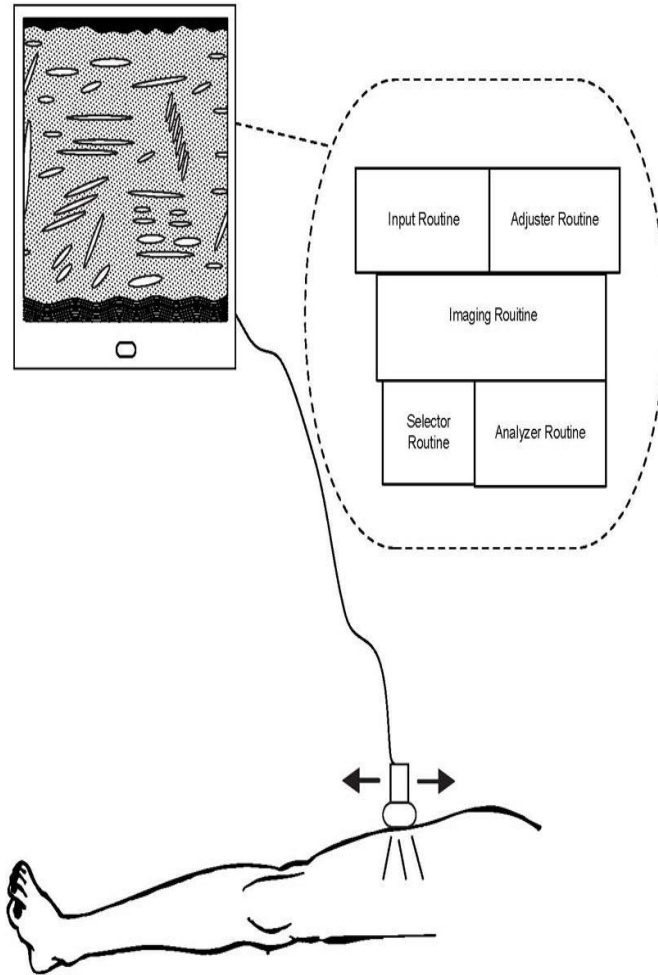


Very invasive and aggressive



Impractical and not possible to apply

A Novel Methodology to Measure Glycogen in a non-invasive way



Hill, J. C., & San Millán, I. S. Validation of musculoskeletal ultrasound to assess and quantify muscle glycogen content. A novel approach. *The Physician and sportsmedicine*, 42(3), 45-52 2014

A Novel Methodology to Measure Glycogen in a non-invasive way





Clinical Features

Validation of Musculoskeletal Ultrasound to Assess and Quantify Muscle Glycogen Content. A Novel Approach

September 2014, Vol. 42, No. 3, Pages 45-52 (doi:10.3810/psm.2014.09.2075)

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S Colorado Boulevard, Tower 1, Suite 4500, Denver, CO 20222. Tel: 720-

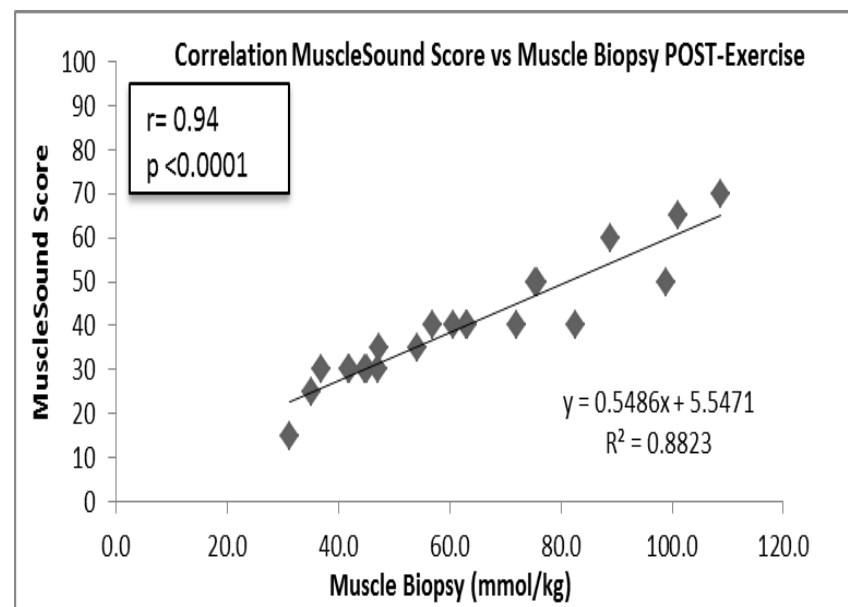
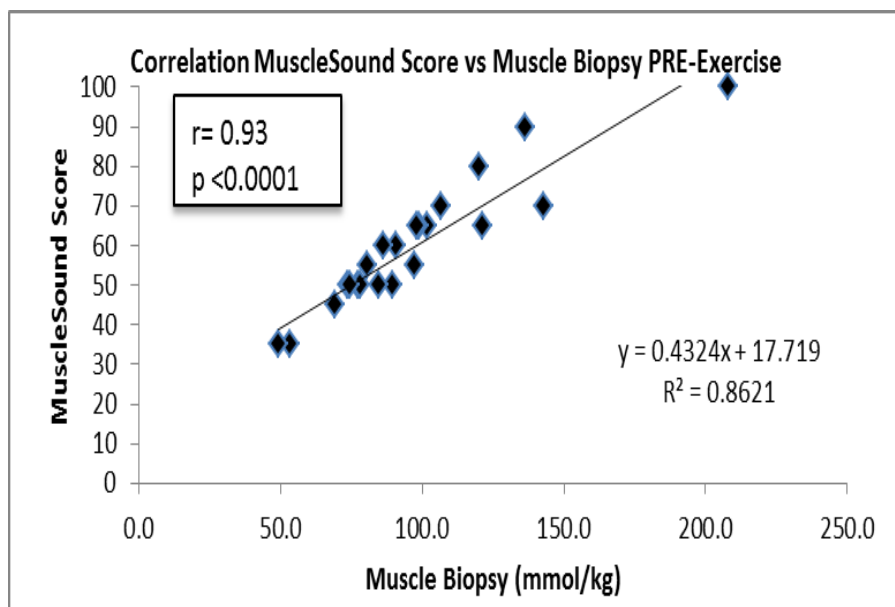
848-8200, Email: john.hill@ucdenver.edu

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Introduction

Methods

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This article is part of the supplement: [35th International Symposium on Intensive Care and Emergency Medicine](#)

Poster presentation

Open Access

Measurement of skeletal muscle glycogen status in critically ill patients: a new approach in critical care monitoring

I San Millan, J Hill and P Wischmeyer

University of Colorado, Aurora, CO, USA

For all author emails, please [log on](#).

Critical Care 2015, **19**(Suppl 1):P400 doi:10.1186/cc14480

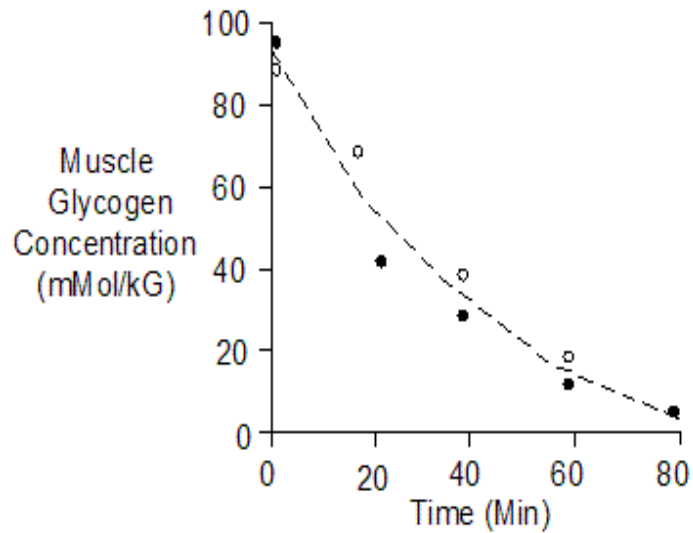
The electronic version of this article is the complete one and can be found online at:

<http://ccforum.com/content/19/S1/P400>

Results

Six out of nine patients had no glycogen present in the muscle (score = 0). The other three patients had glycogen scores between 5 and 15 which are well below scores of healthy individuals (reference 50 to 70). As a comparison we collected post-competition levels in competitive athletes, which decrease their glycogen stores (score 15 to 25) but are well above those of most critically ill patients we have studied.

■ Glycogen and Performance

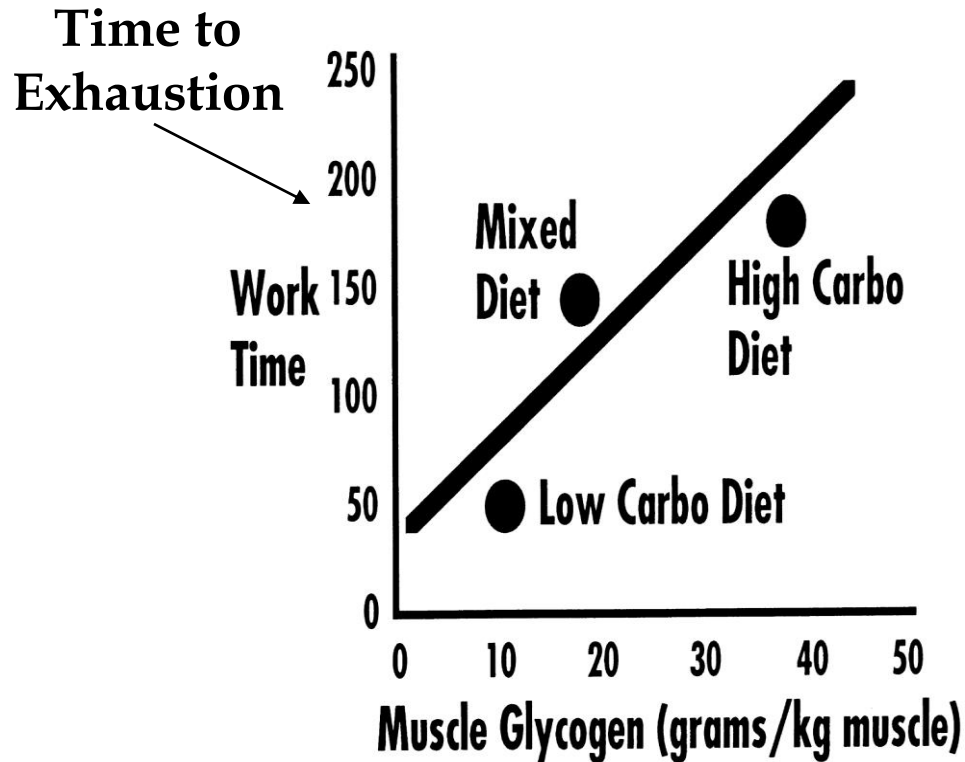


○ Gollnick et. al. 1974

● Hermansen et. al. 1967

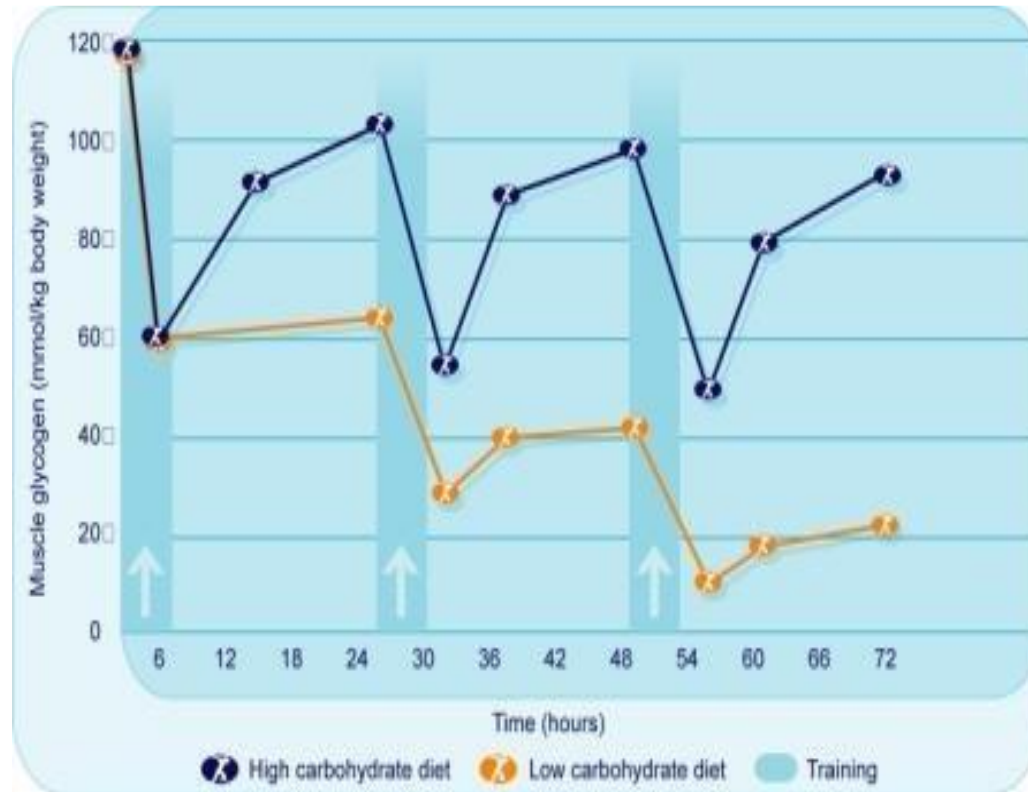


Scientific Study – Glycogen and Performance



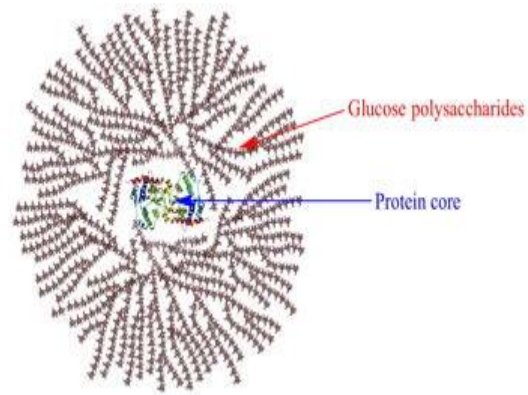
The relationship of muscle glycogen content, work time and dietary carbohydrate intake (adapted from Borgström et al. 1967).

Scientific Study – Glycogen and Performance

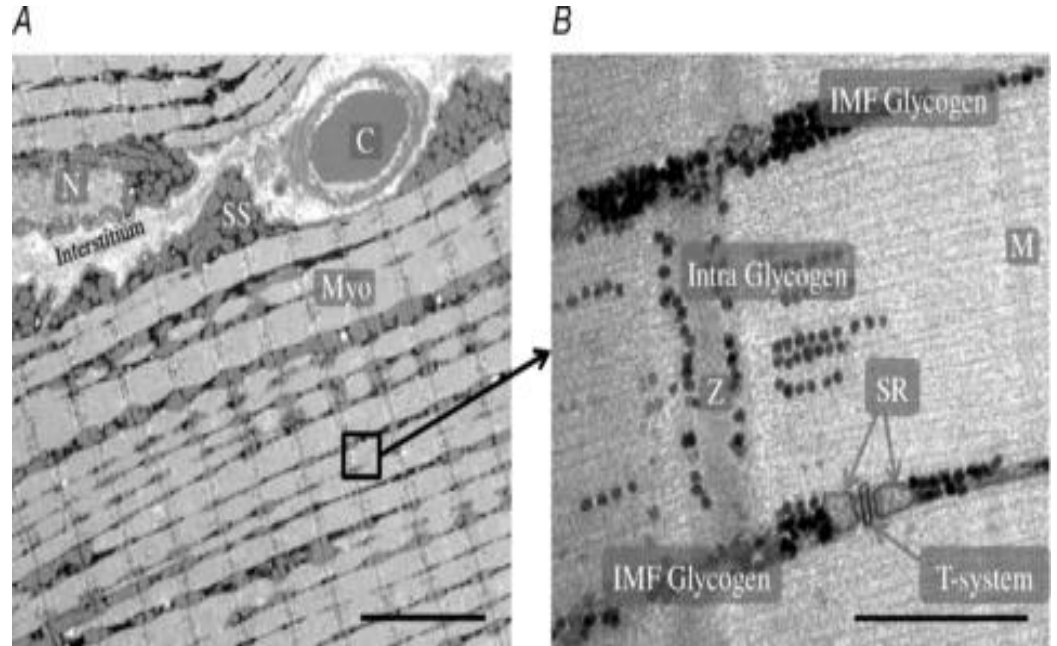
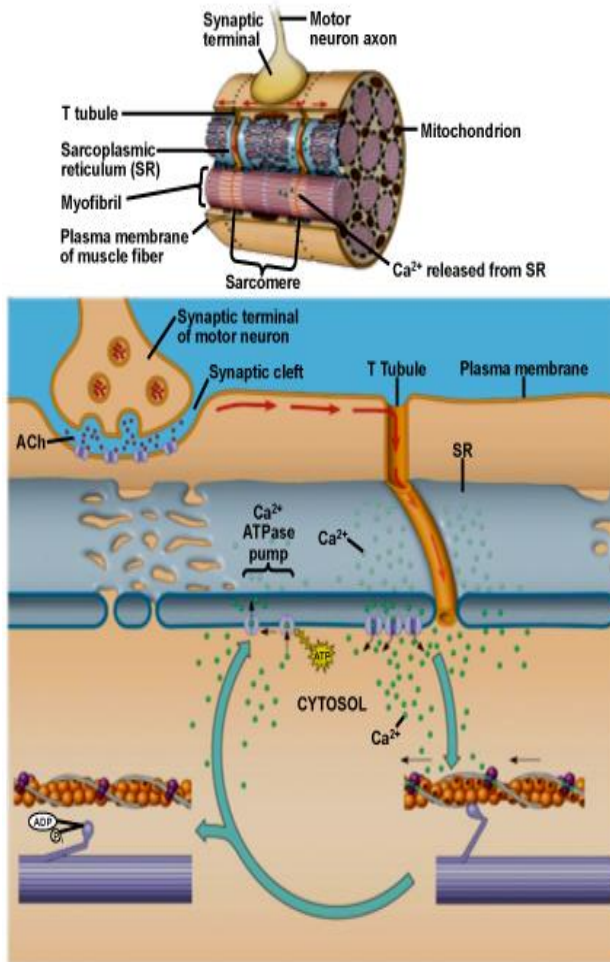


Costill, D. L., and J. M. Miller. "Nutrition for endurance sport: carbohydrate and fluid balance" 1980

Want More on Glycogen?

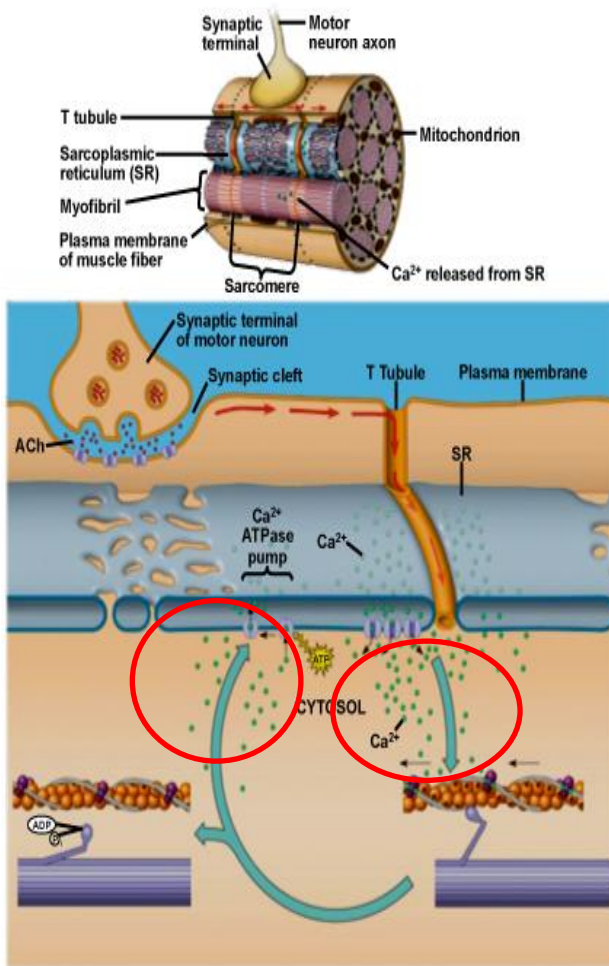


Glycogen Regulates Muscle Contraction

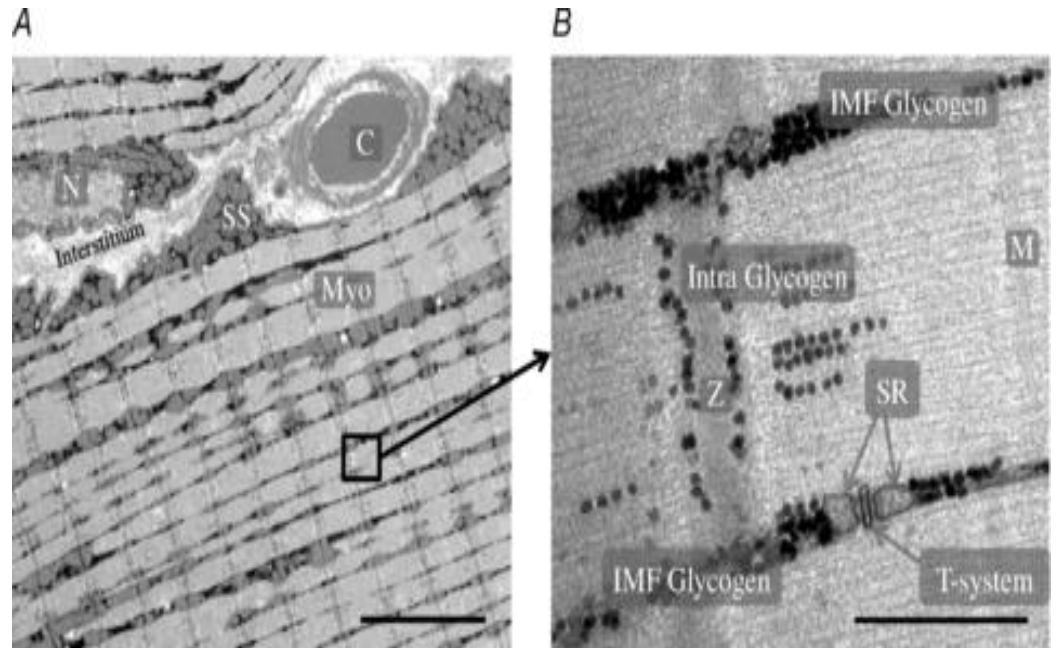


Ørtenblad, Niels, et al. "Role of glycogen availability in sarcoplasmic reticulum Ca²⁺ kinetics in human skeletal muscle." *The Journal of physiology* 2011.

Glycogen Regulates Muscle Contraction



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Ørtenblad, Niels, et al. "Role of glycogen availability in sarcoplasmic reticulum Ca²⁺ kinetics in human skeletal muscle." *The Journal of physiology* 2011.

It is not just about Bonking!

Glycogen Content Regulates Muscle Contraction

J Physiol 589.3 (2011) pp 711–725

Role of glycogen availability in sarcoplasmic reticulum Ca^{2+} kinetics in human skeletal muscle

Niels Ortenblad¹, Joachim Nielsen¹, Bengt Saltin² and Hans-Christer Holmberg^{3,4}

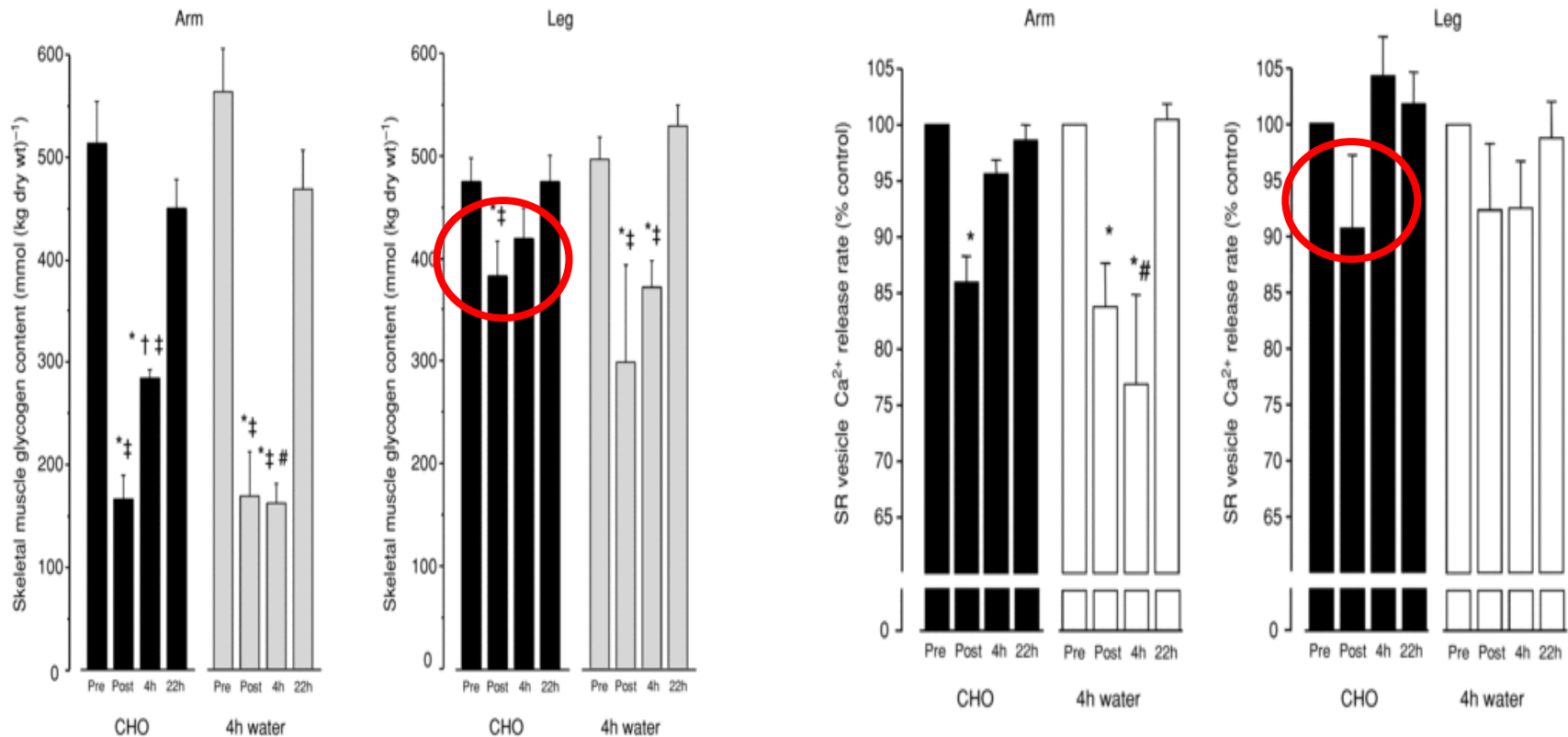
¹University of Southern Denmark, Odense, Denmark

²Copenhagen Muscle Research Centre, Copenhagen, Denmark

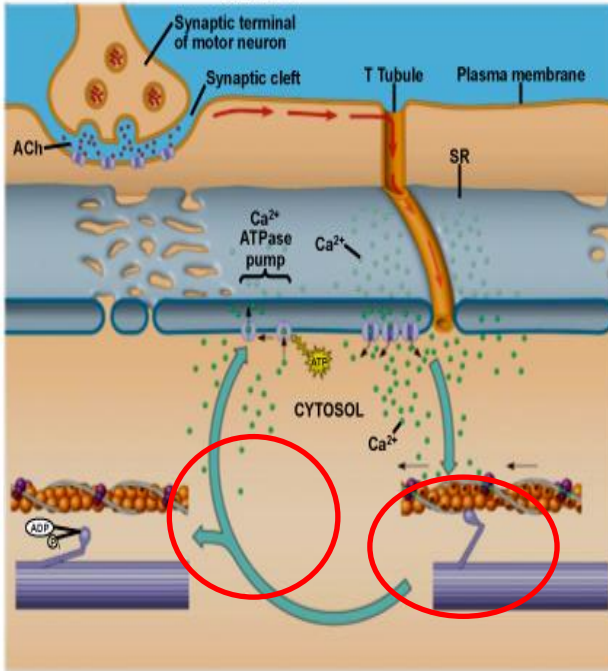
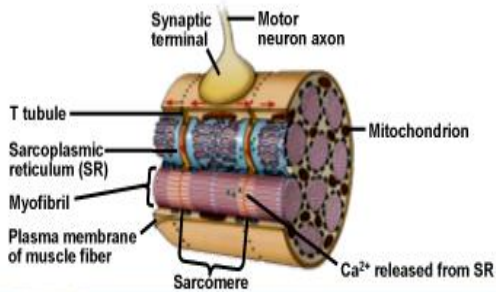
³Swedish Winter Sports Research Centre, Department of Health Sciences, Mid Sweden University, Sweden

⁴Swedish Olympic Committee, Stockholm, Sweden

- A 25% decrease in Glycogen in the legs will decrease Ca^{++} release from SR by a 10%!



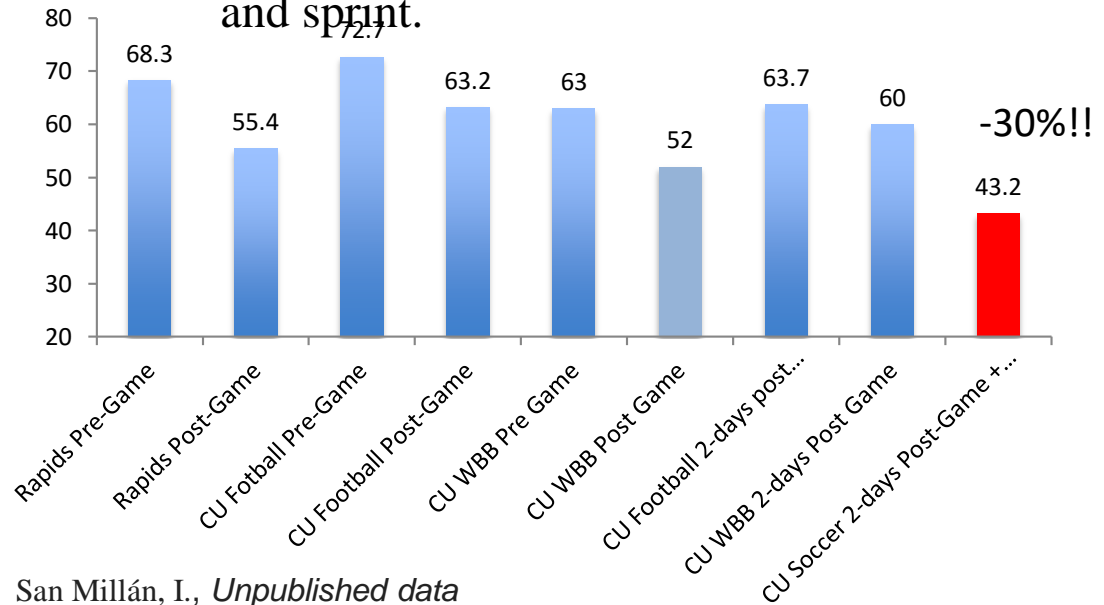
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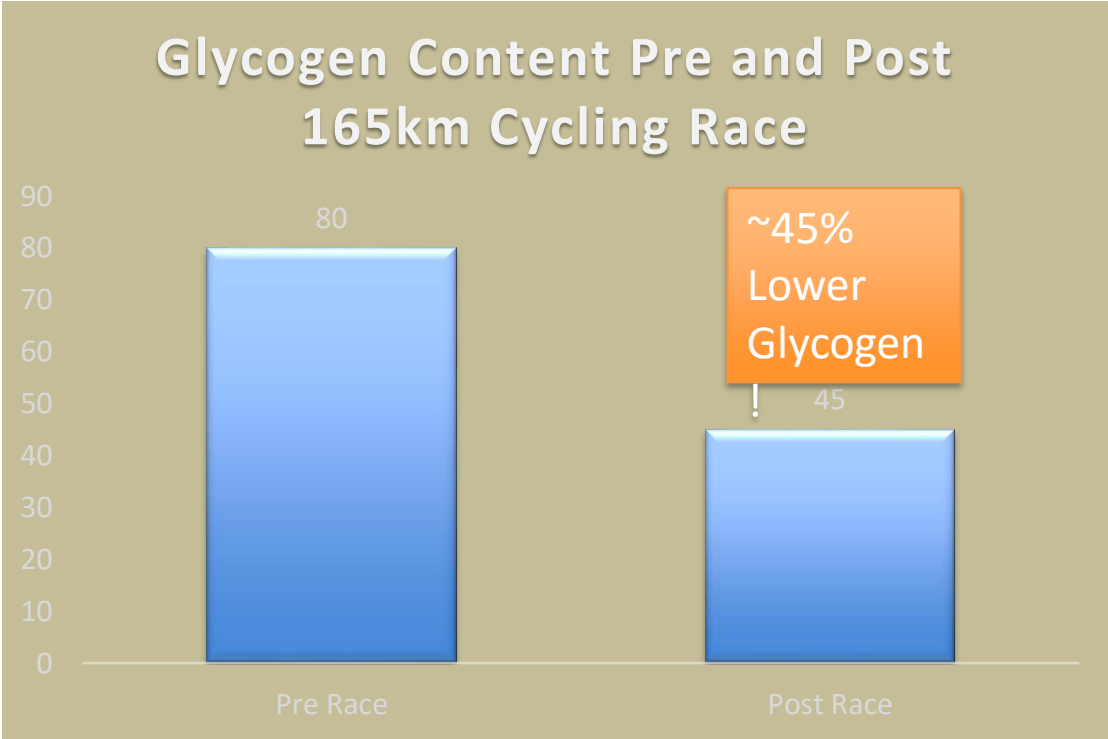
This would represent ~25% decrease in power output and sprint.



San Millán, I., *Unpublished data*

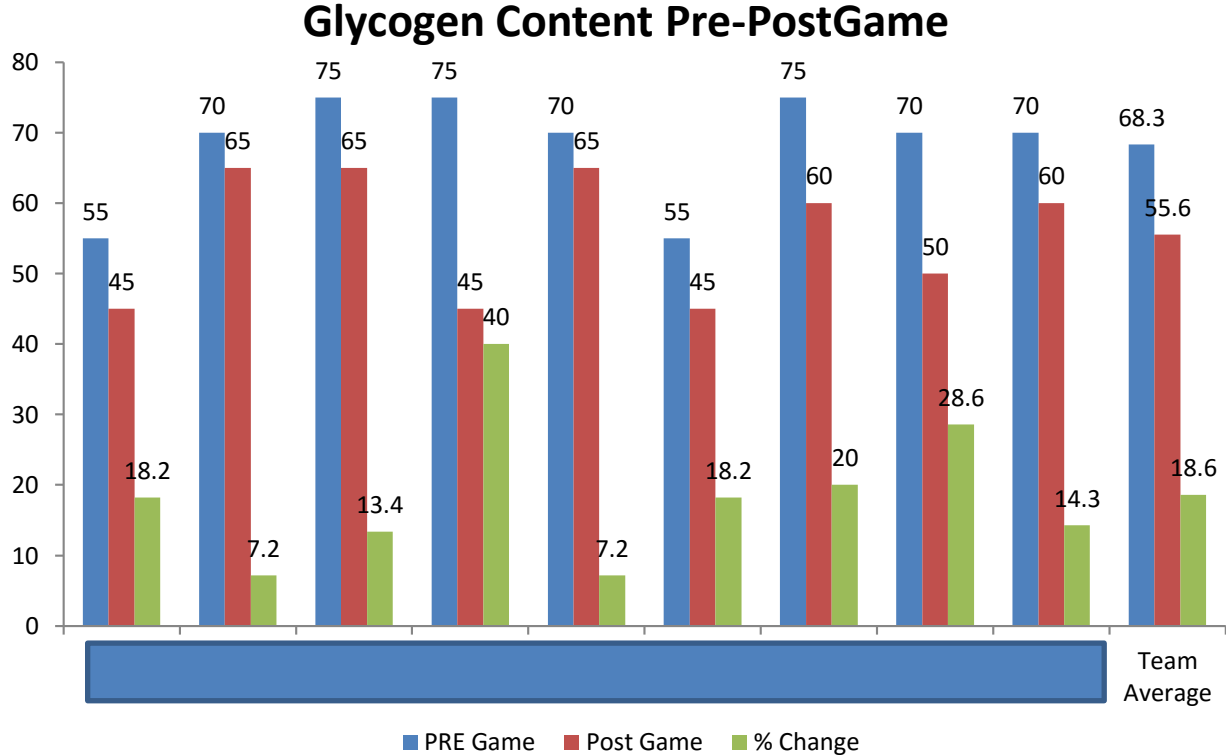
It is not about Bonking!

Glycogen Evolution Throughout Pre and Post-Race



San Millán, I., *Unpublished data*

Glycogen Evolution Throughout Pre and Post-Game



Hill, J. C.; San Millán, I. Changes in Skeletal Muscle Glycogen Content in Professional Soccer Players before and after a Match. Med Sci Sports Exerc ; 2015

INDIRECT ASSESSMENT OF GLYCOGEN STATUS IN COMPETITIVE ATHLETES

I. San Millán¹, C. González-Haro², J. Hill, FACSM¹,

¹School of Medicine, University of Colorado Denver, Denver, CO.; ²Department of Pharmacology and Physiology, School of Medicine, University of Zaragoza, Spain

INTRODUCTION: Proper glycogen storage is of great importance for athletic performance. Multiple studies show the positive correlation between glycogen storage and performance. Nevertheless, glycogen assessment is difficult to determine due to the invasive and impractical nature of muscle biopsies. Therefore, it is difficult to identify suboptimal glycogen levels in athletes. Throughout the measurements of maximal blood lactate levels ($[La]_b \text{ max}$) and maximal carbohydrate oxidation rates ($CHOox \text{ max}$) it could be possible to indirectly estimate muscle glycogen status in competitive athletes and identify suboptimal glycogen levels. The purpose of this study was to assess indirectly muscle glycogen status through measurement of $[La]_b \text{ max}$ and $CHOox \text{ max}$.

METHODS: 82 competitive men (28 professionals and 54 non-professionals) and 17 competitive women carried out a bicycle ergometer test, starting at 2 W·kg⁻¹ with increments of 0.5 W·kg⁻¹ until exhaustion, the duration of three first steps was 5 min, and then 10 min. Oxygen uptake (VO_2) and carbon dioxide (VCO_2) were measured (ParvoMedics TrueOne 2400, Sandy, UT) throughout the test and blood lactate concentration ($[La]_b$) (YSI 1500, Yellow Springs Instruments, Ohio) at the end of each step. $[La]_b \text{ max}$ was considered the value at the end of last step of exercise. Fat and carbohydrate oxidation rates ($FATox$ and $CHOox$) were estimated by means of Frayn's equations. A cutoff of 1 SD respect to the ($[La]_b \text{ max}$) was suggested in order to classify the subjects in two groups: GO (Optimal $[La]_b \text{ max}$) and GS (Suboptimal maximal $[La]_b \text{ max}$) with $[La]_b \text{ max}$ of <5.27 mM in men and <4.00 mM in women respectively as the cutoff. A Student t-test for independent data was used to compare groups, the determination of the Pearson correlation coefficient was used to verify the existence of relationships between variables, level of statistical significance was set at $p < 0.05$.

RESULTS: The results of the present study showed that 30% for men and 24% for women showed suboptimal $[La]_b \text{ max}$ (GS). The correlation between $[La]_b \text{ max}$ and $CHOox \text{ max}$ was high in men ($r=0.771$, $p < 0.05$) and low in women ($r=0.373$). In men, $[La]_b \text{ max}$, $CHOox \text{ max}$, and $RER \text{ max}$ were significantly higher in GO vs. GS, whereas $FATox \text{ max}$ was significantly lower in GO vs. GS. In women, there were not found significant differences neither in $CHOox \text{ max}$ nor in $FATox \text{ max}$. Nevertheless $[La]_b \text{ max}$, and $RER \text{ max}$ were significantly higher in GO vs. GS.

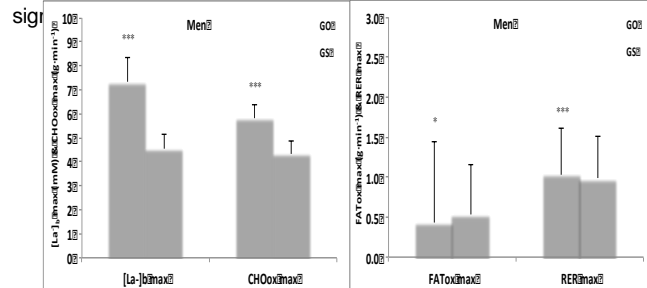
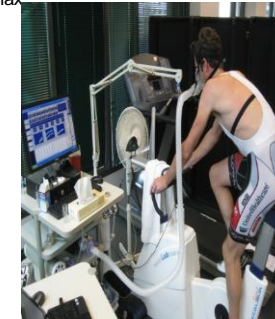


Figure 1. $[La]_b \text{ max}$, $CHOox \text{ max}$, $FATox \text{ max}$ and $RER \text{ max}$ comparisons between both groups of men. * $p < 0.05$, *** $p < 0.001$.

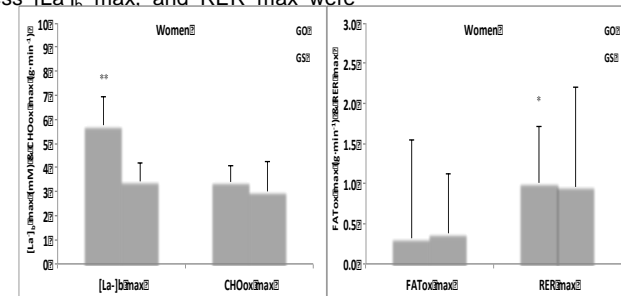


Figure 2. $[La]_b \text{ max}$, $CHOox \text{ max}$, $FATox \text{ max}$ and $RER \text{ max}$ comparisons between both groups of women. * $p < 0.05$, ** $p < 0.01$.

CONCLUSION: The measurement of $[La]_b \text{ max}$ and $CHOox \text{ max}$ in competitive athletes could be a good and practical approach to indirectly evaluate glycogen status as well as to identify suboptimal glycogen storages that can ultimately affect athletic performance.

ACKNOWLEDGEMENTS: The authors would like to express their gratitude to all subjects for their cooperation in this study.

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¹School of Medicine, University of Colorado Denver, Denver, CO.; ²Department of Pharmacology and Physiology, School of Medicine, University of Zaragoza, Spain

INTRODUCTION: Proper glycogen storage is of great importance for athletic performance. Multiple studies show the positive correlation between glycogen storage and performance. Nevertheless, glycogen assessment is difficult to determine due to the invasive and impractical nature of muscle biopsies. Therefore, it is difficult to identify suboptimal glycogen levels in athletes. Throughout the measurements of maximal blood lactate levels ($[La]_b \text{ max}$) and maximal carbohydrate oxidation rates ($CHOox \text{ max}$) it could be possible to indirectly estimate muscle glycogen status in competitive athletes and identify suboptimal glycogen levels. The purpose of this study was to assess indirectly muscle glycogen status through measurement of $[La]_b \text{ max}$ and $CHOox \text{ max}$.

METHODS: 82 competitive men (28 professionals and 54 non-professionals) and 17 competitive women carried out a bicycle ergometer test, starting at 2 W·kg⁻¹ with increments of 0.5 W·kg⁻¹ until exhaustion, the duration of three first steps was 5 min, and then 10 min. Oxygen uptake (VO_2) and carbon dioxide (VCO_2) were measured (ParvoMedics TrueOne 2400, Sandy, UT) throughout the test and blood lactate concentration ($[La]_b$) (YSI 1500, Yellow Springs Instruments, Ohio) at the end of each step. $[La]_b \text{ max}$ was considered the value at the end of last step of exercise. Fat and carbohydrate oxidation rates ($FATox$ and $CHOox$) were estimated by means of Frayn's equations. A cutoff of 1 SD respect to the ($[La]_b \text{ max}$) was suggested in order to classify the subjects in two groups: GO (Optimal $[La]_b \text{ max}$) and GS (Suboptimal maximal $[La]_b \text{ max}$) with $[La]_b \text{ max}$ of <5.27 mM in men and <4.00 mM in women respectively as the cutoff. A Student t-test for independent data was used to compare groups, the determination of the Pearson correlation coefficient was used to verify the existence of relationships between variables, level of statistical significance was set at $p < 0.05$.

RESULTS: The results of the present study showed that 30% for men and 24% for women showed suboptimal $[La]_b \text{ max}$ (GS). The correlation between $[La]_b \text{ max}$ and $CHOox \text{ max}$ was high in men ($r=0.771$, $p < 0.05$) and low in women ($r=0.373$). In men, $[La]_b \text{ max}$, $CHOox \text{ max}$, and $RER \text{ max}$ were significantly higher in GO vs. GS, whereas $FATox \text{ max}$ was significantly lower in GO vs. GS. In women, there were not found significant differences neither in $CHOox \text{ max}$ nor in $FATox \text{ max}$. Nevertheless $[La]_b \text{ max}$ and $RER \text{ max}$ were significantly higher in GO vs. GS.

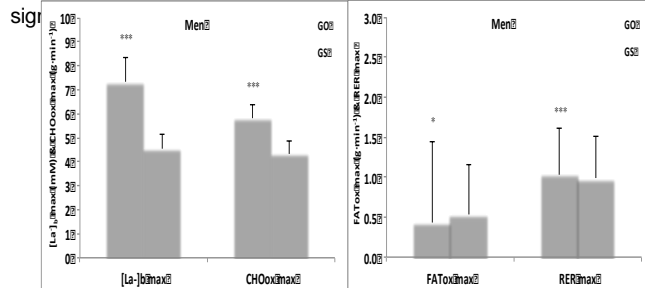
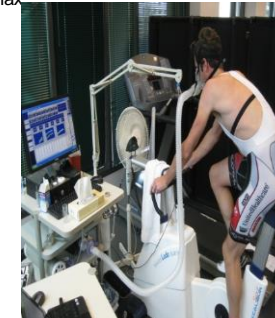


Figure 1. $[La]_b \text{ max}$, $CHOox \text{ max}$, $FATox \text{ max}$ and $RER \text{ max}$ comparisons between both groups of men. * $p < 0.05$, *** $p < 0.001$.

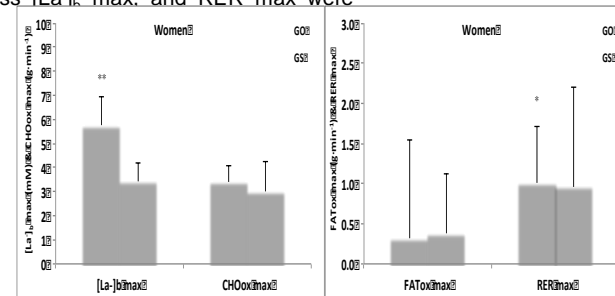


Figure 2. $[La]_b \text{ max}$, $CHOox \text{ max}$, $FATox \text{ max}$ and $RER \text{ max}$ comparisons between both groups of women. * $p < 0.05$, ** $p < 0.01$.

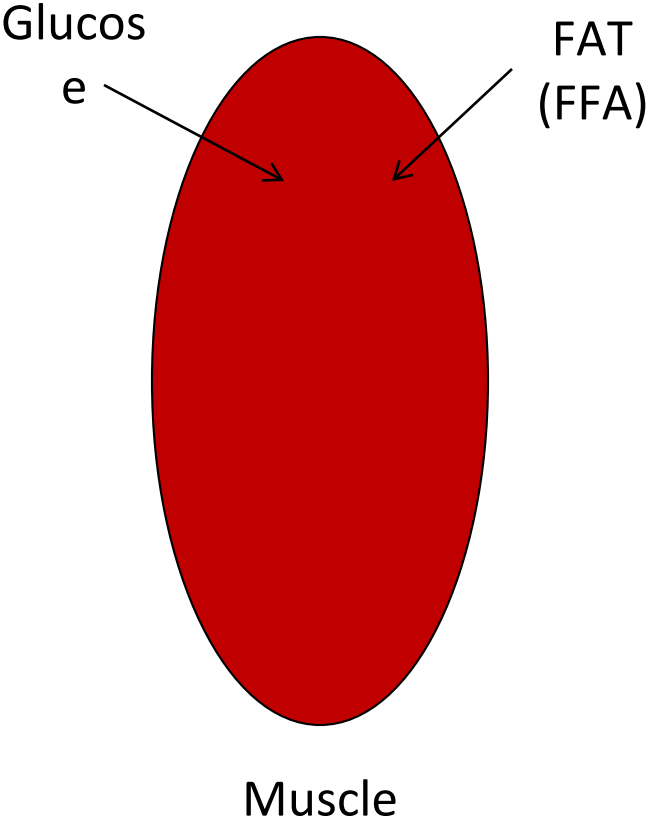
CONCLUSION: The measurement of $[La]_b \text{ max}$ and $CHOox \text{ max}$ in competitive athletes could be a good and practical approach to indirectly evaluate glycogen status as well as to identify suboptimal glycogen storages that can ultimately affect athletic performance.

ACKNOWLEDGEMENTS: The authors would like to express their gratitude to all subjects for their cooperation in this study.

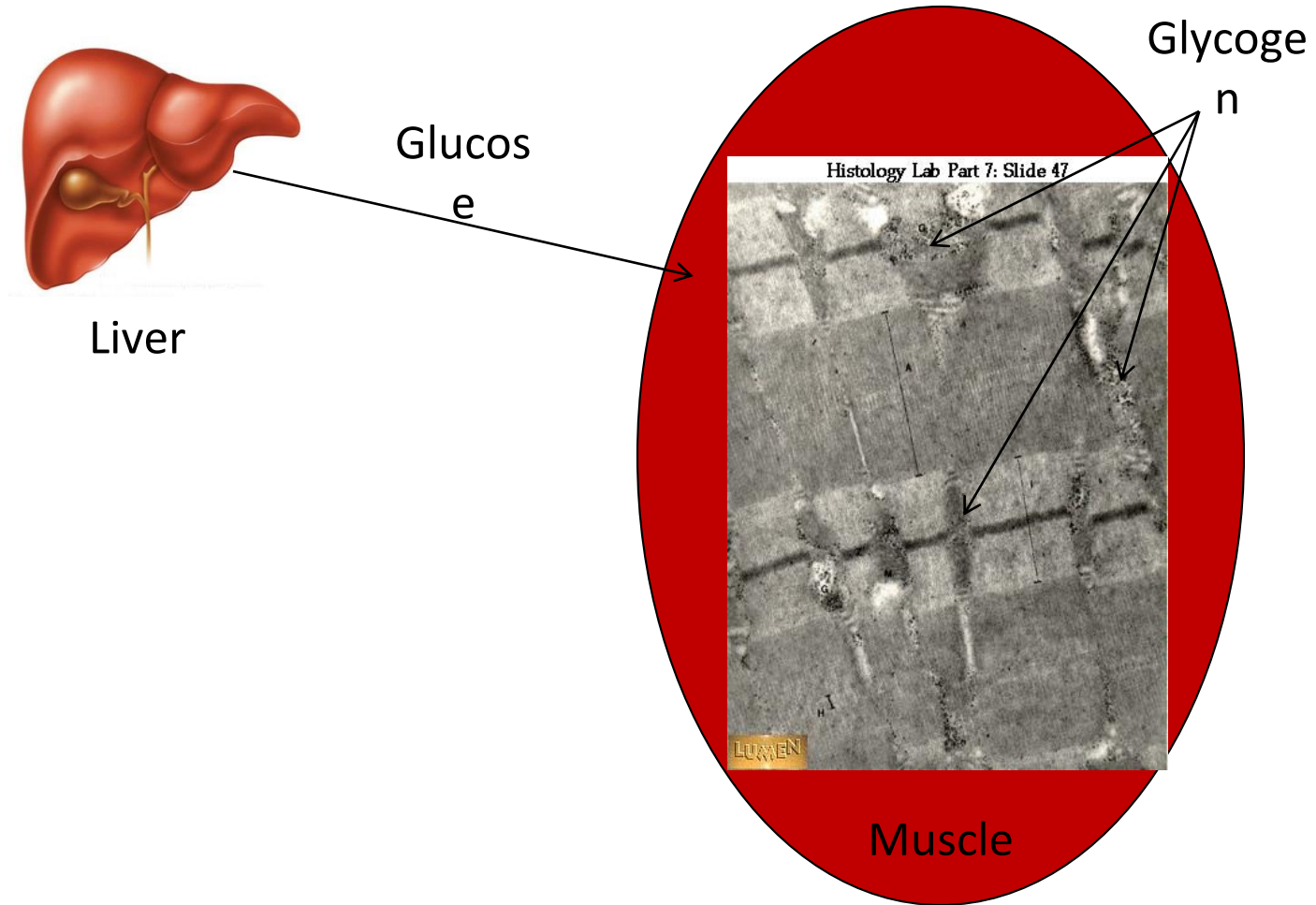
Glycogen and Overtraining/Muscle Damage



Glycogen and Overtraining/Muscle Damage



Glycogen and Overtraining/Muscle Damage

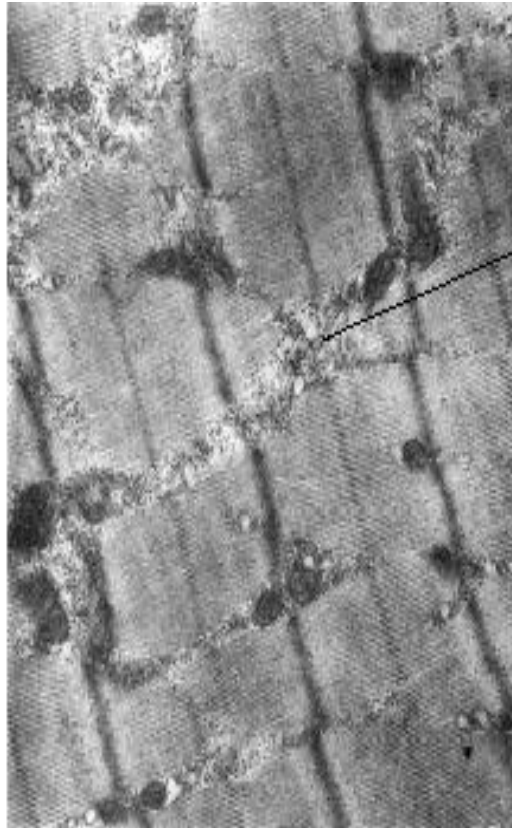


Glycogen and Overtraining/Muscle Damage

Before Intense/long Exercise

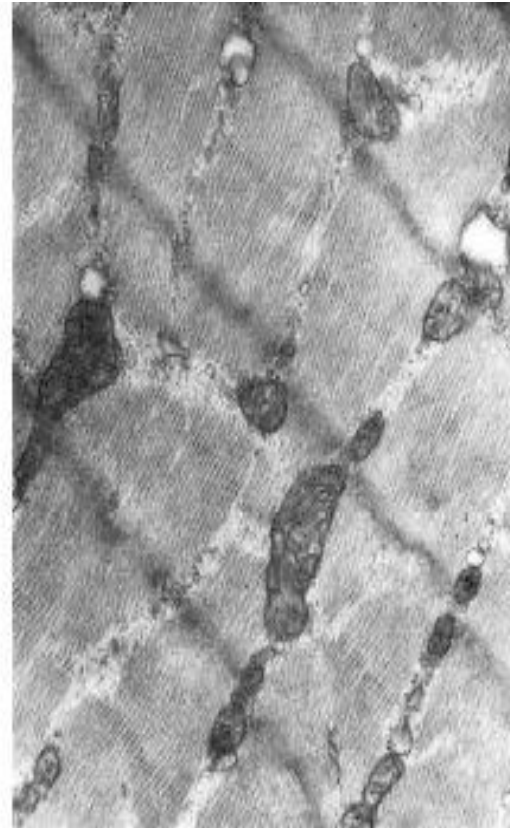
After Intense/Long Exercise

(a)



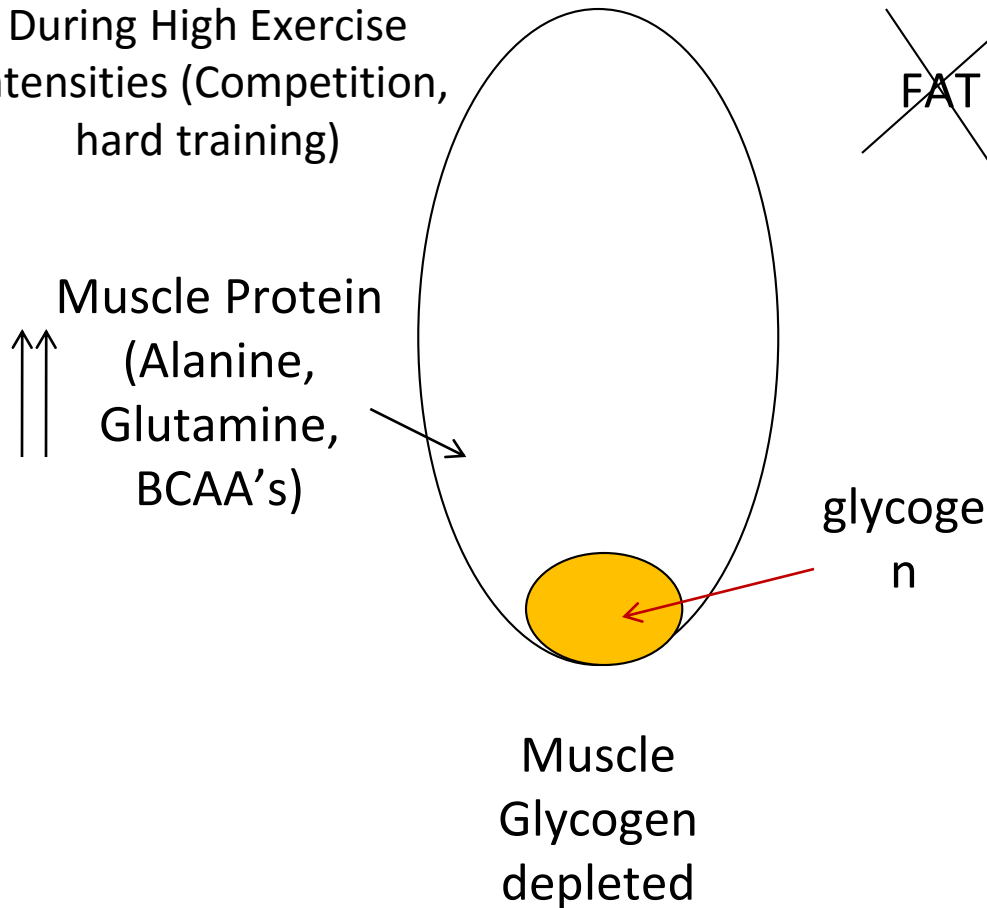
Glycogen granules

(b)



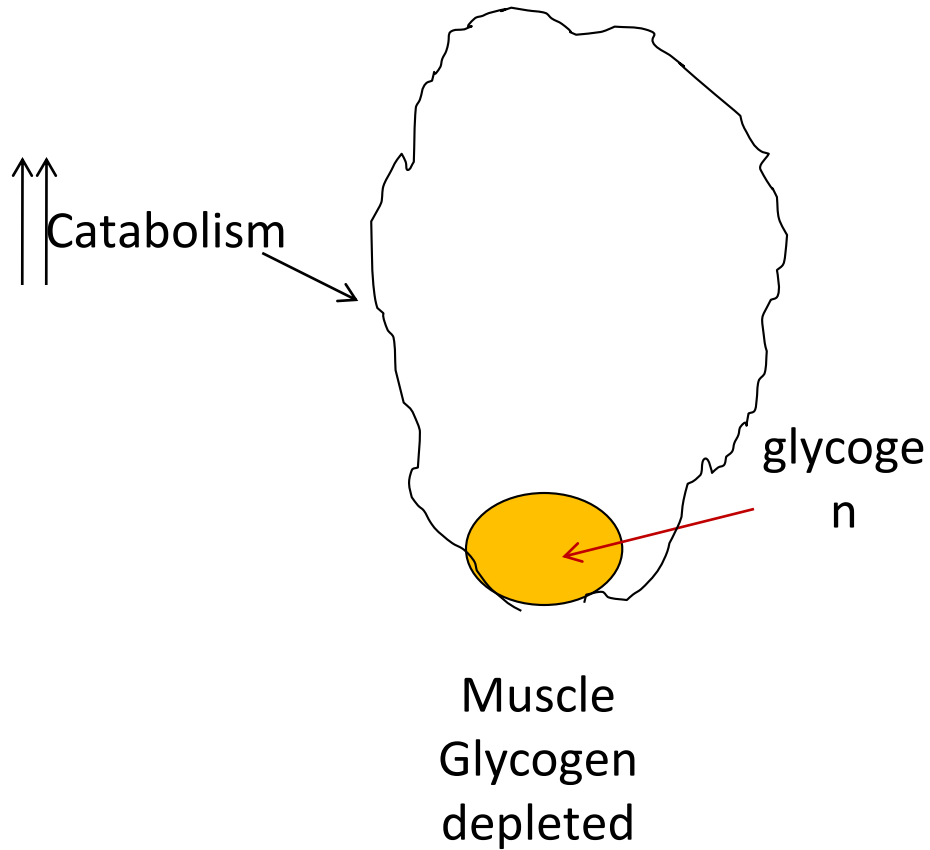
Glycogen and Overtraining/Muscle Damage

During High Exercise intensities (Competition, hard training)



With normal Glycogen protein utilization ~3-5%
With low Glycogen content protein utilization can be up to 20%!

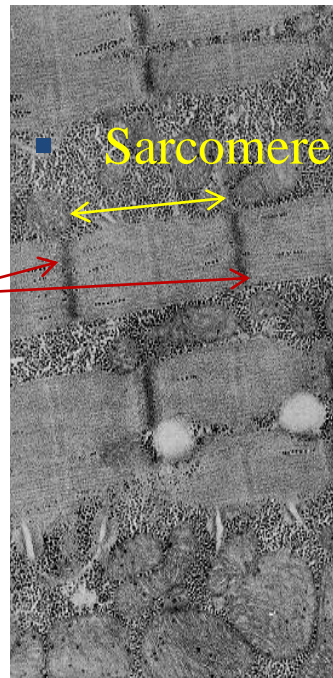
Glycogen and Overtraining/Muscle Damage



Glycogen and Overtraining/Muscle Damage

Muscle Damage

- Healthy muscle



- Z-Lines

- Muscle Injury

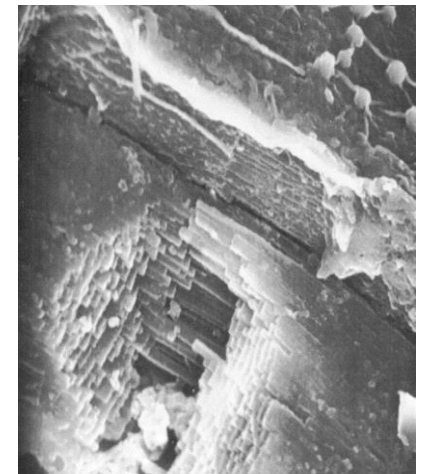


Figure 4.11 (a) An electron micrograph showing the normal arrangement of the actin and myosin filaments and Z disk configuration in the muscle of a runner before a marathon race. (b) A muscle sample taken immediately after a marathon race shows Z disk streaming caused by the eccentric actions of running. Reprinted from Hagerman et al. (1984).

Summary

- Carbohydrates are crucial for physical performance
- NO scientific study shows that restricting CHO increases performance
- Low CHO diets increases chances of overtraining
- Glycogen concentration regulates muscle contraction capacity
- Decreased CHO/Glycogen may increase muscle damage
- Carbohydrates weren't sent by Aliens from outerspace to exterminate humankind!



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