MEASUREMENT OF POST-EXERCISE GLYCOGEN RESYNTHESIS FOLLOWING INGESTION OF GLUCOSE POLYMERS WITH DIFFERENT MOLECULAR WEIGHTS AND OSMOLALITY: A ^{13}C MRS STUDY.

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Introduction: The rate of muscle glycogen resynthesis following exercise is of great importance for optimising performance in athletes. Previous studies have shown that a high molecular weight (HMW) glucose polymer (500-700kg mol^{-1}) with low osmolality (84 mosmol kg^{-1}) empties from the stomach more quickly[1], and leads to greater increases in blood glucose and insulin[2] during the first 30 minutes following ingestion compared with an isoenergetic lower molecular weight (LMW, 0.5kg mol^{-1}), higher osmolality (350 mosmol kg^{-1}) glucose solution. These HMW polymers have also been shown to increase muscle glycogen resynthesis rates over the first 2h[3] following exercise relative to LMW. However, in this study glycogen levels were assessed from biopsies, limiting the number of samples that could be acquired. This study aims to use the excellent temporal resolution offered by ^{13}C Magnetic Resonance Spectroscopy (MRS) of muscle glycogen at 7T to observe early differences in post-exercise glycogen resynthesis rates due to ingestion of glucose polymers with different molecular weights.

Methods: Subjects: 9 Healthy, recreationally active, male volunteers (age=25±4 years, BMI=24.2±1.9 kg m^{-2}, VO_2 max=45.7±5.8 ml kg min) provided informed, written consent, and underwent preliminary testing to establish VO_2 max before attending three experimental study visits (one visit per drink), separated by at least 1 week. Subjects arrived at the scanning visits following overnight fasting and having refrained from alcohol, caffeine and strenuous exercise for 24h. Subjects were requested to consume the same food intake in the day prior to each study visit. Experimental Protocol: On each study visit, subjects were positioned prone, with their right thigh placed within the surface coil (marked for repositioning) at the isocentre of the magnet. An initial T_1-weighted TFE image was acquired to check the position of the muscle within the coil, as well as for glycogen quantitation, followed by acquisition of a ^{13}C spectrum for measurement of muscle glycogen. Subjects were then removed from the scanner and mounted an electrically braked cycle ergometer to begin cycling at 75% VO_2 max. Subjects each cycled for a total of 1.5h, with 5 minute breaks when they were unable to maintain pedal frequency above 50 rev min^{-1}. Following completion of the exercise, subjects ingested one of the three 1l solutions: **HMW**, consisting of 100g of HMW, low osmolality, glucose polymer (500kgmol^{-1}, 74mosmol kg^{-1}, Vitargo, Swecarb AB, Kalmar, Sweden); **LMW**, containing 100g of LMW, high osmolality glucose polymer (0.9g mol^{-1}, 153 mosmol kg^{-1}, Maxijul, SHS International, Liverpool, UK), and a control (**CON**) consisting of flavoured water. The drinks were ingested within 3min, before subjects were immediately repositioned within the scanner. A second T_1-weighted TFE image was acquired before 1h of continuous ^{13}C MRS acquisition for measurement of post-exercise glycogen resynthesis rates. MR Methods: All MR measurements were acquired on a Philips Achieva 7T system, using a transmit/receive quadrature ^{13}C coil with transmit/receive quadrature ^{1}H decouple coils. ^{13}C spectra were acquired using a proton-decoupled pulse acquire sequence with adiabatic pulses and narrowband decoupling (BW=16000Hz, samples=256, TR=1000ms) for measurement of glycogen concentrations. 8 spectra, each with 80 averages, were collected at baseline (total scan time = 10.66min). Post-exercise spectra were collected continuously for 1h. Spectra were zero-filled (to 4096 points) and linebroadened (100Hz Lorentzian) before phase correction in jMRUI. Post exercise spectra were then averaged into 10.66 min blocks with a 5.33 min offset and peak areas for glycogen and the external reference marker (vial containing ^{13}C labeled urea positioned within the coil) were calculated using an in-house built Matlab program. Statistics: Significant differences were assessed using a t-test in SPSS 17, with significance defined as $p<0.05$. Results are uncorrected for multiple comparisons.

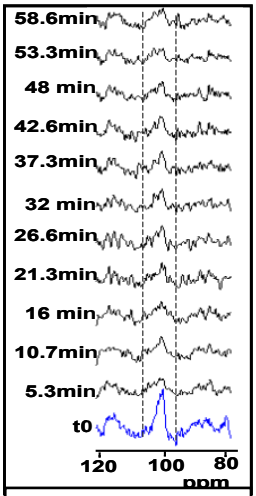

Fig. 1: Temporal changes in glycogen. Results shown for a single subject.

Results and Discussion: Basal glycogen levels: No significant difference in basal (pre-exercise) glycogen levels were found between the 1st, 2nd and 3rd visits for each subject (mean ± SD = 153±71mmol/l, 157±50 mmol/l and 142±69mmol/l for the three visits respectively). Similarly, when grouped by subsequent drink, no significant differences in basal glycogen levels were found (CON = 156 ± 50 mmol/l, LMW = 155 ± 70 mmol/l and HMW=140 ± 71 mmol/l). Post-exercise glycogen levels: Glycogen levels were significantly reduced following exercise in all three visits for each subject (reduced to 24±13%, 28±20% and 34±24% of baseline levels). Post exercise levels were not significantly different when grouped by drink (CON=27±19%, LMW=33±20% and HMW = 25±20% of baseline levels). Rates of glycogen resynthesis following carbohydrate ingestion: Figure 1 shows example spectra from a single subject following ingestion of HMW. The mean group glycogen levels (as a percentage of pre-exercise concentrations) following ingestion of the drink, are shown in figure 2. Following 1h of recovery and ingestion of CON, muscle glycogen concentrations were not significantly different from post-exercise levels at t=5.3min (43±42 mmol/l vs 42±30 mmol/l at 5.3 min and 58.6 min respectively, p=0.96). In contrast, glycogen concentrations in the muscle were significantly increased following the LMW drink (from 47±27 mmo/l to 69±27 mmol/l, p=0.002) and the HMW drink (from 33±26 mmol/l to 47±27 mmol/l, p=0.02). No difference in glycogen concentration increases (mmol/l) could be measured between the LMW and the HMW drinks. Similarly, fitting post-exercise changes in glycogen concentrations to a linear fit (y=mx+c) indicates no differences in glycogen resynthesis rates between the drinks (mean ± SD resynthesis rates across group: CON=0.003±0.2 glycosyl units min^{-1}, LMW = 0.3±0.2 glycosyl units min^{-1}, and HMW = 0.2±0.3 glycosyl units min^{-1}). Glycogen resynthesis rates for both glucose solutions were lower than expected, which is likely due to reduced gastric emptying when subjects were positioned prone (subjects were positioned semi-supine for previous studies[2]). Findings of increased muscle glycogen from Piehl-Aulin, are likely different from those found in this study, firstly, as they provided subjects with a standard breakfast, which could lead to altered glycogen resynthesis following the drinks due to second meal effects[5,6], and secondly, because the quantity of carbohydrate ingested was much greater (75g every 30 minutes up to 90 minutes). This would lead to much greater increases in glycogen concentration from depleted levels, and thus would likely increase the size of the difference between drinks.

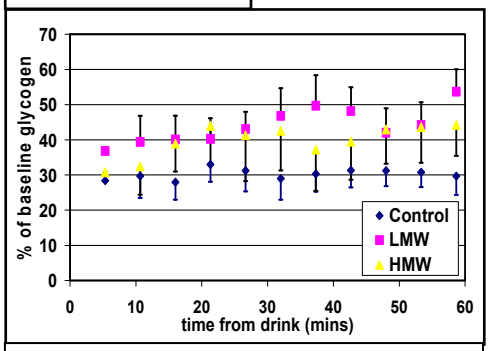

Fig. 2: Plot showing post-exercise glycogen resynthesis following ingestion of HMW and LMW glucose solutions compared to a flavoured water control (CON). Data shown are mean ± SE.

Conclusions: Despite significant increases in muscle glycogen levels following post-exercise ingestion of glucose polymers with different molecular weights (HMW and LWM), the rates of glycogen resynthesis during the first hour following ingestion were not significantly different between the two carbohydrate drinks. Gastric emptying may have been affected by subject positioning (prone), reducing initial differences in glycogen resynthesis rates.

References: 1. Lieper, JP. Piehl-Aulin K and Soderland, K. *Scand. J. Gastroent.* (2000), **35**, pp1143-1149. **2.** Stephens FB, *et al. J. Sports Science* (2008), **26**(2), pp149-154. **3.** Piehl-Aulin, K. Soderland K. and Hultman E, *Eur. J. Appl. Physiol.* (2000), **81** pp346-351. **4.** Price, TB. *et al. J. Appl. Physiol.* (1994) **76**(1), pp 104-111. **5.** Abriara C, Buchanan B, and Hodges L. *Am J Clin Nutr* (1987) 45: pp952–957. **6.** Carey, PE *et al, Am J Physiol Endocrinol Metab* (2003) 284:E688-E694.