Integrated Diaphragmatic Function, Chemosensitivity, and Endurance in Exercising Divers

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Background: While exercising underwater, divers experience increased ventilatory load which can predispose them to respiratory muscle fatigue and hypercapnia. Hypercapnic ventilatory response (HCVR) is a highly variable measure of the physiological response to increased PCO2, and a lower HCVR is associated with increased PCO2 while diving. Respiratory muscle training (RMT) has been shown to augment endurance in divers and is also associated with increased HCVR in those with a low baseline HCVR. A prior study in our lab showed sub-toxic CO exposure has beneficial effects on skeletal muscle. This study aimed to test the hypothesis that RMT (with and without CO) would improve chemosensitivity (HCVR), integrated diaphragmatic function (IDF), and diving exercise endurance with those receiving sub-toxic CO seeing the greatest benefit.

Methods: Fit male (n=21) and female (n=9) subjects (VO_2 peak ≥ 35 mL$*$kg$^{-1}*$min^{-1} and 30 mL$*$kg$^{-1}*$min^{-1} respectively) ages 18 to 45 years were recruited. Baseline spirometry, HCVR, VO_2peak dry and submersed at ambient pressure, and IDF were assessed followed by bicycle exercise endurance at 85% VO_2peak submersed in a hyperbaric chamber compressed to an equivalent depth of 55 feet of seawater (fsw) with intermittent blood gas, lactate, and pyruvate samples. Subjects then completed twenty 30-minute RMT sessions over one month breathing either air or 200 ppm CO. The same battery of tests was performed upon completion of RMT. Blood samples were analyzed for stopped-flow analysis of O_2 offloading from hemoglobin (Hb) and compared with mouse erythrocytes.

Results: A total of 30 subjects completed all phases. Preliminary results show RMT increasing respiratory muscle static pressures, HCVR for those with low baselines, and endurance duration. Post-RMT subjects had higher mean arterial pCO_2 ($p=0.0005$) while exercising with no change in ventilation rate ($p=0.0967$).

Summary/Conclusions: As predicted, RMT has a beneficial effect for divers and was able to improve chemosensitivity, integrated diaphragmatic function, and exercise endurance at depth. Surprisingly, mean pCO_2 during exercise increased following RMT without a change in ventilation—potential explanations will need to be explored. Overall, RMT improves underwater endurance, possibly due to changes in chemosensitivity, IDF, and skeletal muscle enhancement. Since the study is still blinded, the effect of CO is still pending.

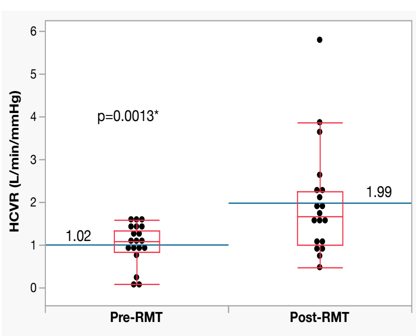

Figure 1. Pre-RMT vs post-RMT HCVR values for subjects that began with low baseline HCVR.

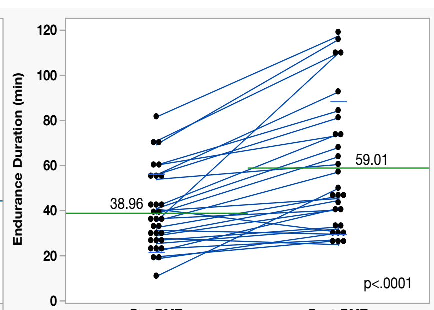

Figure 2. Pre-RMT vs post-RMT submerged endurance exercise duration.

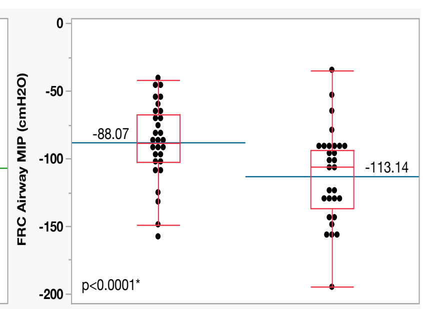

Figure 3. Pre-RMT vs post-RMT maximum inspiratory pressure (MIP).