Using Transthoracic Echocardiography (TTE) During Head Out Immersed Exercise in Cold Water to Study Swimming Induced Pulmonary Edema (SIPE)

M.J. Lynch, H.C. Charles, R.A. Roller, J.J. Freiberger, S.D. Martina, M.J. Natoli, E.A. Schinazi, J.A. Kisslo, R.E. Moon

Department s of Anesthesiology, Medicine and Radiology and Center for Hyperbaric Medicine & Environmental Physiology, Duke University Medical Center, Durham, NC, USA

DUKE DEPARTMENT OF ANESTHESIOLOGY 1971-2011

Abstract

TITLE: USING TRANSTHORACIC ECHOCARDIOGRAPHY (TTE) DURING HEAD OUT IMMERSED EXERCISE IN COLD WATER TO STUDY SWIMMING INDUCED PULMONARY EDEMA (SIPE)
AUTHORS: M.L. Lynch, R.A. Roller, J.J. Freiberger, S. Martina, M.J. Natoli, E.A. Schinazi, J.A. Kisslo, R.E. Moon Dept. of Anesthesiology, Duke University Hospital, Durham, North Carolina 27710
INTRODUCTION: Immersion pulmonary edema (IPE) also known as swimming induced pulmonary edema (SIPE) is a condition in which cough, hemoptysis, dyspnea and hypoxemia develop while swimming or diving. Counter intuitively it is common in Special Forces swimmers during training and triathletes, considered the elites in physical fitness conditioning. Incidence is reported from 1.8% to 60% but typically <5%. The pathophysiology of this condition is unknown. What is known is that the normal exercise-related increase in pulmonary artery and wedge pressures are augmented by immersion induced volume redistribution from the lower extremities into the central circulation. The purpose of this study was to use head out immersed exercise in cold water as a provocative test and immersed TTE during exercise to monitor cardiac responses. We hypothesized that individuals susceptible to SIPE respond to cold water immersion exercise with excessive elevations of PA pressures caused by decreased left ventricular compliance.
METHODS: Normal volunteers were pre-selected to have a tricuspid regurgitant jet which would allow echocardiographic estimation of PA pressures. Subjects exercised for 40 minutes on a bicycle ergometer during head out immersion in 20.4±0.9°C (mean±SD) water. Echo parameters were measured at dry rest, immersed before exercise, early and late during exercise and during post-exercise rest (immersed). Measured parameters included right ventricular systolic pressure RSVP), early and late transmitral peak velocities (E and A) early septal mitral annulus velocity (E'), IVC diameter (during inspiration and expiration), longitudinal and circumferential strain. E/E' and E/A ratios were calculated. Echocardiographic examination of lung parenchyma looking for "comet tails" as an indication of increased lung water was performed. One individual subject (S), a 53 year old female triathelete that had experienced 3 episodes of SIPE, was analyzed separately. Statistical analysis was performed using repeated measures ANOVA (JMP 10, SAS, Cary NC). Results are reported as mean±SD. IRB approval was obtained before proceeding.
1H MRI was obtained on a Seimens TRIO (3 Tesla) using an ultra short echo sequence (TR 2.54 ms, TE .07 ms, 3.125 mm^3 voxels, Flip Angles 1,3,6,9 degrees, scan time 3:49 per flip angle).
RESULTS: 17 subjects to date have completed the protocol, not all parameters could be measured in all subjects. RVSP was 21.4±3.6 mmHg at dry rest, 26.2± 7.6 during immersion and 32.6±5.7 at max exercise (P=0.0005). Subject S had RSVP values of 24, 39, 62 mmHg respectively. E/A ratio dry, during immersed rest before and at max exercise were 1.95±0.58, 1.85±0.35 and 1.45±0.50 respectively, P=0.005 corresponding values in subject S were 1.5, 1.8 and 1.4. E/E' did not change in normal subjects. Subject S had lower E/A during dry rest 1.5 vs. 1.95±0.58 and higher E/E' 9 vs. 5.38±1.63 (greater than age expected increase) compared to controls. No comet tails were seen.
CONCLUSIONS: Results confirm a progressive increase in pulmonary artery pressure during immersed exercise in cold water assessed by TTE. Compared to controls, the subject with prior SIPE history showed an exaggerated PA response and elevated E/E' consistent with decreased LV compliance.

Background

- Swimming induced pulmonary edema/immersion pulmonary edema (SIPE/IPE) is a condition where cough, hemoptysis, dyspnea and hypoxemia develop while swimming or diving
- Counter intuitively it occurs in extremely fit individuals, triathletes and Special Forces swimmers during open water swims. Contributing or precipitating factors that have been reported include cold water, exertion levels, wet suit tightness and unrecognized medical co morbidities
- Manifestations, usually with hemoptysis, occur in the water and resolve with minimal medical intervention after leaving the aquatic environment. An individual can have more than one episode
- Pathogenesis is unknown but involves an abnormal response to immersion. Immersion will normally auto transfuse up to 800 mL blood from the peripheral venous system into the central circulation instantaneously
- Individual susceptibility may be due to decreased left ventricular compliance or failure at the level of the pulmonary capillary
- We hypothesize that susceptible individuals have an exaggerated increase in pulmonary artery pressures caused by reduced left ventricular compliance

Methods

Fig. 1. Subjects during immersed exercise pedaling a submerged bicycle ergometer. Mouth piece and tubing allows measurement of ventilation, oxygen consumption and DLCO (used to assess lung water). The echo cardiographer is in the water on the subject's right

Fig. 2. MRI used to validate lung water measurements in a limited number of subjects

Fig. 3 Venous blood samples drawn intermittently to monitor HbCO levels to correct DLCO and test for genetic markers

- After IRB approval and informed consent normal subjects and one subject who previously experienced SIPE exercised in 20°C water for 40 minutes on a bicycle ergometer to heart rate 131±20 bpm, $\dot{V}O_2$ 2.45±0.73 $L.min^{-1}$ STPD (mean±SD)
- TTE performed at dry rest, rest immersed in cold water, early ("min") and late ("max") during exercise and immersed post exercise
- Measured parameters included right ventricular systolic pressure (RSVP), early and late transmitral peak velocities (E and A), early septal mitral annulus velocity (E'), IVC diameter (inspiration and expiration), longitudinal and circumferential strain. E/E', E/A ratios calculated
- Echocardiographic examination of lung parenchyma looking for "comet tails" as indication of increased lung water
- MRI performed in selected subjects to quantify and validate lung water measurements

Results

Loss of IVC Respiratory Variation

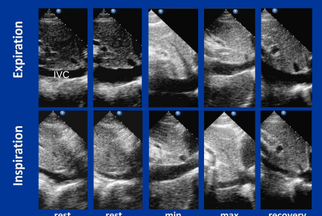

Fig. 4. Subject S: Serial changes in IVC during protocol. Rest dry, IVC not dilated and contracts >50% on inspiration; rest wet, markedly dilated with profound respiratory variation; min wet dilated and minimal changes during respiration; max wet interestingly went down in size but minimum respiratory change; recovery wet remained dilated but good respiratory movement. By echo criteria, this indicates increasing RA pressures with decrease in respiratory variation

Tricuspid Regurgitation

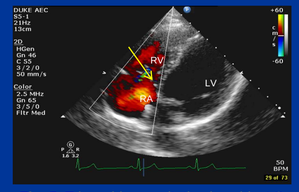

Fig. 5. Tricuspid regurgitation in subject S with a history of previous SIPE

Comets Dry and Wet

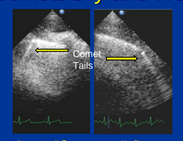

Fig. 6. "Comet tails" seen rarely, both before (left) and after immersion (right)

Increase in TR Velocity

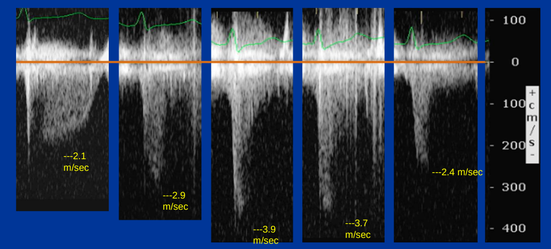

Fig. 7. Subject S: Serial increase in TR velocity during protocol indicating increase in RVSP (see IVC loss of respiratory variation). The scale has been adjusted to be identical for each picture

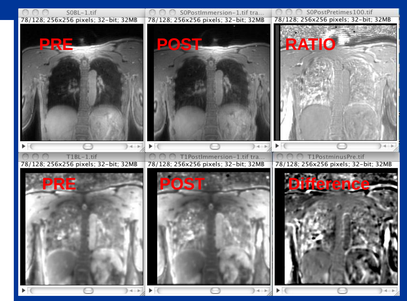

Figure 8: Examples of pre immersion and post immersion proton (water) density images (top row) and T1 images (bottom row). The far right images show changes in the post immersion images. For example in the left lung of the slice shown in the figure the water density increased in 43% of lung tissue.

Table 1: TTE parameters Control vs. Subject "S" (mean±SD). *P<0.05 vs. Dry Rest

Condition	RVSP-Control (mmHg)	RVSP "S" (mmHg)	IVC Insp Control (cm)	IVC Insp "S" (cm)	IVC Exp Control (cm)	IVC Exp "S" (cm)	IVC Ratio exp/insp Control	IVC Ratio exp/insp "S"	E/A ratio Control	E/A ratio "S"	E/e' Control	E/e' "S"	Long. Strain Control	Long. Strain "S"	Circ. Strain Control	Circ. Strain "S"
Dry Rest	21.4±3.6	24	0.57±0.22	0.49	1.69±0.37	1.2	0.33±0.10	0.41	2.0±0.6	1.5	5.4±1.6	9	-19.5±1.5	-21.5	-20.2±2.1	-26.2
Wet Rest	26.2±5.9*	39	1.06±0.47*	1.7	2.10±0.32*	2.2	0.50±0.22*	0.77	1.8±0.4	1.8	5.1±2.6	11	-20.2±1.6	-22.0	-20.2±3.0	-27.8
Wet Ex Early	26.9±7.0*	56	0.78±0.35	0.95	1.91±0.50	1.5	0.40±0.10	0.63	1.5±0.6*	1.5	6.8±2.7	12	-21.7±1.3*	-24.2	-23.4±3.2*	X
Wet Ex Late	32.6±5.7*	62	0.61±0.21	1.3	1.80±0.43	1.6	0.34±0.10	0.81	1.5±0.4	1.4	11.7±4.8*	10	-23.3±1.1*	-24.3	-27.3±1.6*	-35.1
Wet Post Ex	26.6±7.9*	33	0.55±0.19	1.2	1.86±0.45	1.5	0.30±0.07	0.80	1.4±0.5*	1.4	5.7±1.4	8	-19.4±1.4	-22.1	-20.2±2.3	-30.7

Conclusions

- We have demonstrated the feasibility of performing quantitative echocardiography during immersed exercise. Changes in E/A and E/e' during immersed exercise suggest impaired diastolic filling even in normals
- Preliminary results suggest that IPE-susceptible individuals may be identifiable using this technique. An IPE susceptible individual showed an increase in RVSP and E/e' with immersion, consistent with impairment of diastolic filling
- Intrapulmonary comet-tails may be spurious and an unreliable indicator of mild pulmonary edema
- Preliminary results from pulmonary MRI are consistent with mild pulmonary edema after 40 minutes of exercise in cold water in an IPE-susceptible individual

Acknowledgment

- Supported by NAVSEA contract #N0463A-10-C-0005

NAVSEA NAVAL SEA SYSTEMS COMMAND

DUKE

Extraordinary Care – Through a Culture of Innovation