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Feasibility study of CPR in the water

N. F. MARCH AND R. C. MATTHEWS

Department of Medicine, M-023, University of California, San Diego, La Jolla, CA 92093

March NF, Matthews RC. Feasibility study of CPR in the water. Undersea Biomed Res 1980; 7(2):141–148.—More than 8000 drownings occur each year in the United States alone. With the increased popularity of scuba diving for commercial and sport purposes, one would predict an increase in related deaths or accidents. Yet procedures to administer first aid are limited to mouth-to-mouth, and external cardiac compressions must await moving the victim to a firm surface. This study discusses the technique of placing a victim upon the rescuer's chest and initiating full cardiopulmonary resuscitation (CPR) immediately on the site. During emergency regulator resuscitation (E.R.R.), ventilations are administered by use of a slightly modified, factory-calibrated scuba regulator. The techniques were tested on an instrumented aquatic CPR mannequin and found to meet the published criteria for successful CPR.

cardiopulmonary resuscitation (CPR)
scuba
aquatic rescue

Cardiopulmonary resuscitation (CPR) administered correctly can sustain vital functions when the heart loses its capacity to provide adequate systemic perfusion (1). This technique requires that a rescuer begin external cardiac compressions within 4 min and thereafter maintain adequate ventilation and sufficient sternal compression and rate to guarantee cerebral bloodflow (2, 3). Cardiorespiratory arrest can occur in aquatic situations from trauma, drowning (4), or asphyxia (5). However, the American Medical Association, American National Red Cross, and American Heart Association currently do not describe an acceptable method for CPR in the water (6, 7). In scuba-related accidents, any delay in time involved between the event, transportation of the victim to shore or boat, and initiation of conventional treatment is nearly always fatal, or seriously impairs successful recovery due to lack of therapy (8).

The purpose of this project was to validate not only techniques that utilize the rescuer's chest as a backboard for cardiac compressions, but also a factory-calibrated, safety-designed scuba regulator as an emergency ventilatory device, as possible methods for sustaining unconscious or incapacitated individuals in aquatic environments.

MATERIALS AND METHODS

These studies used a Laerdal recording resuscitation mannequin (Model No. 2000000) (Laedral Medical Corporation) redesigned for submersion in aquatic environments. The mannequin measures 173 cm in length, with a dry weight of 52 kg. Upon immersion the mannequin's weight is slightly negative. Statham transducers (P-23 ID) were connected to the mannequin's airway and compression mechanisms to measure tracheal airway pressure and sternal deflection, respectively. Data were recorded on a 2-channel polygraph recorder (Brushmark 222). Correct sternal positioning was measured on a 5-cm^2 contact switch, which was connected to an indicator light, monitored by an investigator, and marked manually on the polygraph strip.

A pressure-limited, safety-designed scuba regulator provided positive pressure ventilations. The scuba regulator (SCUBAPRO Air Inhalation Regulator, A.I.R. 1 Model 11-126-000) was factory-calibrated to deliver a peak inspiratory pressure of 40 mmHg and 780 ± 20 liters/min air flow from the mouthpiece upon complete depression of the trigger or "purge" mechanism. The criteria used to establish these values were those of the National Research Council *Standards for Cardiopulmonary Resuscitation and Emergency Cardiac Care* (6). These modifications in the purge characteristics of the SCUBAPRO regulator have negligible effects on the breathing resistance (less than 1 cm H_2O), which makes this a feasible alteration to all high-flow regulators. Conventional scuba regulators were not utilized during these experiments because of the high gas-delivery pressure during purging developed by some regulators and the lack of sufficient pressure in others. Peak gas delivery pressures above 50 mmHg could possibly rupture lungs (9), and pressures below 20 mmHg might not provide adequate ventilation (10). Emergency regulator resuscitation (E.R.R.) was administered by placing the regulator within the mannequin's mouth, hyperextending the neck to achieve a patent airway, and fully depressing the purge mechanism for 1 s/ventilation without nose occlusion (Fig. 1). Because of the high rate of air flow from the regulator, the nose was left unobstructed, thereby acting as an overpressure valve while allowing the lung to inflate fully without risking barotrauma. We recorded and tabulated respiratory rate and expired volumes using a 6-liter water-filled spirometer (W.E. Collins Model P-600). A Laerdal lung (040402-1000 ml) with a one-way

Fig. 1. Emergency regulator resuscitation, E.R.R., using a factory-calibrated safety-designed scuba regulator.

valve mounted on its distal aspect was connected to the spirometer with a length of Tygon tubing.

Six subjects, all with previous scuba diving experience, were instructed in the performance of external cardiac compressions and E.R.R. on the mannequin while it was stationary and out of water. Their ability to perform these techniques then was measured over a 15-min period. All individuals subsequently were tested while administering CPR and supplying propulsion in the water with the recording resuscitation mannequin as the victim. All rescuers wore full wetsuits and inflated back or wrap-around jacket flotation devices during testing in the water. Several body and hand positions were used during these studies for correct sternal positioning and relative ease of applying cardiac compressions. The body positions utilized were an under-arm maneuver and a cross-chest maneuver (Figs. 2A, 2C). The hand positions include the "Butterfly" and "Clenched-Fist" (Figs. 2B, 2D). Each rescuer was allowed to select either position. Laboratory experiments were conducted with audio-feedback signals to the rescuer, which indicated correct position, compression, and ventilation. All aquatic sessions consisted of single-blind testing procedures, with no audio-feedback signals to the rescuer.

RESULTS

All data were pooled from the six rescuers; the data consisted of three runs per rescuer for both aquatic and laboratory sessions. The collective means and ranges are reported ($n = 18$). Laboratory observations of compression depth vs. time (Fig. 3A) show a slight decay overall from 4.4 cm to 3.0 cm, with all but one remaining within the acceptable range (i.e. 3–6 cm) for sternal compressions. Aquatic sessions produced compression depths of up to 4.5 cm in the beginning, and all remained slightly higher than corresponding laboratory results for the remainder of the experimental period.

Compression rate, measured as sternal deflections/min, remained relatively constant between 45 and 55 deflections/min during the laboratory sessions, but decreased slightly during aquatic trials to between 34 and 48 deflections/min (Fig. 3B). Respiratory rate was constant in the laboratory at 8 ventilations/min and fluctuated between 6 and 8 ventilations/min during aquatic trials (Fig. 4A). Expired volumes from the laboratory sessions were between 5 and 6 liters/min, while the pool sessions produced volumes between 4 and 6 liters/min (Fig. 4B). Rescuer-supplied propulsion shows straightline distances between 365 and 560 m/15 min traveled in the pool while aquatic CPR was administered.

COMMENTS

Currently, there exists no medically approved method of cardiopulmonary resuscitation applicable in water without firm support for the victim's back. Thus, the onset of CPR is delayed until the victim is transported out of water and onto a solid surface. This study suggests that the described methods can be used successfully if a rescuer has access to a modified second-stage scuba regulator, an adequate supply of compressed air, and flotation equipment commonly used by scuba divers today. This application allows the rescuer the requisite freedom of both hands in conducting effective external heart massage while remaining in an aquatic environment.

Sternal compression depth ranged from approximately 2.0 to 4.5 cm, with most values falling within the established limits for resuscitation (3–6 cm). The compression rate ranged from 34 to 55 deflections/min, even over a 15-min period; again, most deflections fell within

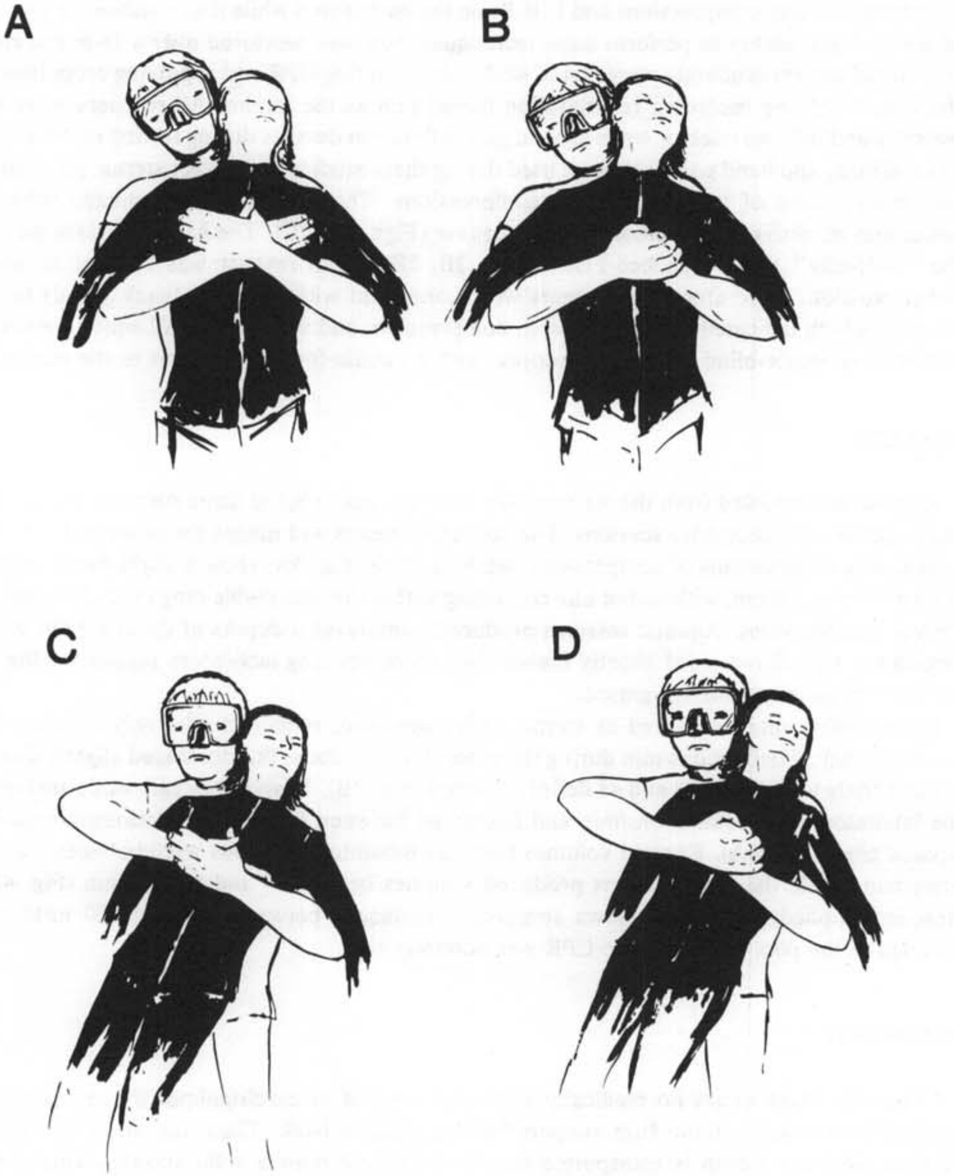
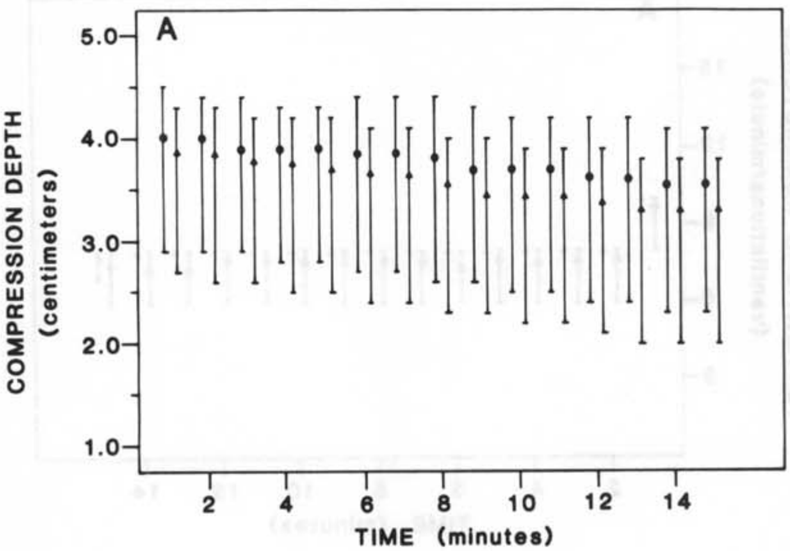


Fig. 2. A: Under-arm body positioning for aquatic CPR, using the Butterfly hand position. **B:** Clenched-Fist hand position. **C:** Cross-chest body positioning for aquatic CPR using the Butterfly hand position. **D:** Clenched-Fist hand position.



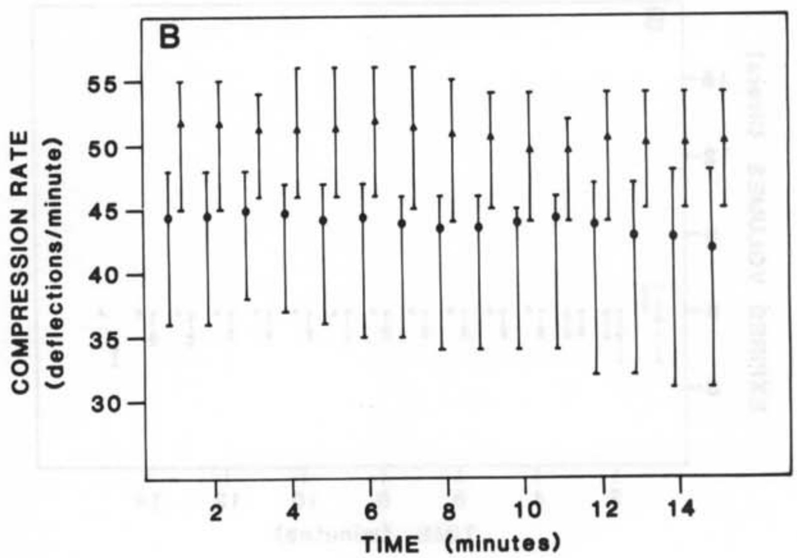


Fig. 3. **A:** Compression depth generated by rescuers on a submersible recording resuscitation mannequin while administering aquatic CPR. Note that the decay in sternal deflection is greater in the laboratory trials than in the aquatic sessions. Lab trials (▲), Pool sessions (●). **B:** Compression rate maintained by rescuers administering aquatic CPR to simulated victim. Note that the rate in the laboratory was slightly higher because of the audio-feedback system used during laboratory sessions. Lab trials (▲), Pool sessions (●).

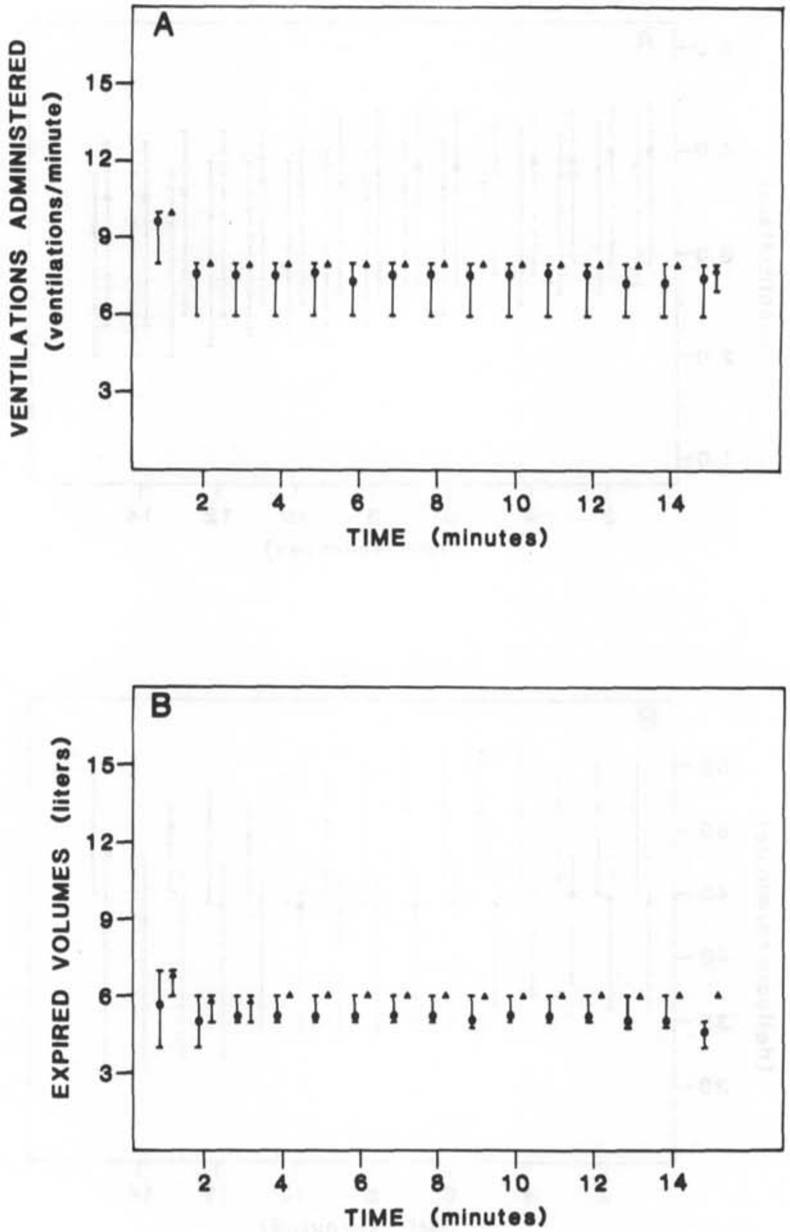


Fig. 4. **A:** Ventilations administered during aquatic CPR using a safety-designed scuba regulator for positive pressure ventilation. The range is larger in the pool during the first 3 min because of the unfamiliarity of the mannequin to some rescuers. Higher minute-1 values are due to the initial administration of four quick ventilations following standard CPR technique. Because of an auditory timing mechanism, each rescuer achieved identical values. Pool session (●), Lab session (▲). **B:** Expired volumes from simulated lung (Laedal 1000 ml) during the administration of aquatic CPR. Full inflations of the lung were achieved only if the mannequin's neck was hyperextended, which maintained a patent airway. Rescuers received audio-feedback signals during the laboratory trials, which indicated successful filling of the lung. Because of this, most rescuers achieved identical values. Pool session (●), Lab session (▲).

physiological values (40–80 beat/min). Respiratory rates between 6 and 8 ventilations/min and expired volumes between 4 and 6 liters/min show that the factory-calibrated scuba regulator—E.R.R. device can be safely used to administer emergency ventilation to the victim of an aquatic accident. Use of the high flow regulator made occlusion of the nose, mouth, and exhaust ports unnecessary. As flow increases, so does resistance to flow. The unblocked exhaust ports and open nose impose sufficient resistance to high flows to cause the lungs to inflate, without the possibility of lung over-expansion.

Comparing the E.R.R. technique to a constant-volume respirator (Harvard No. 607) and a demand resuscitation respirator (Elder Valve, Model No. 34-103) in ventilating anesthesized, aspirated dogs, we found that the modified scuba regulator could maintain blood-gas values as well as the demand resuscitation device. Considering that the E.R.R. device and the demand respirator both successfully maintained ventilation in the experimental animals and that the first is capable of full operation when in water, while the latter is not, we believe a modified scuba regulator could be a valuable tool immediately available at many aquatic accidents.

This study demonstrates the applicability of methodology for successful maintenance of an incapacitated victim for a period of at least 15 min at the surface of an aquatic environment by a single rescuer. Data collected during this study indicate that these described methods are applicable in many aquatic emergencies. Subsequent studies with the U.S. Coast Guard demonstrated the techniques to be successful in choppy and rolling seas. Because of the tremendous interest in aquatic or marine environments for recreational or occupational pursuits, accidents are inevitable. Rapid response by a properly trained and equipped individual could mean the difference between successful first aid and rescue, or certain death.

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March NF, Matthews RC. Etude de fiabilite du CPR dans l'eau. Undersea Biomed Res 1980; 7(2):141–148.—Plus de 8.000 noyades surviennent chaque année rien qu'aux Etats-Unis. La croissance en popularité de la plongée sous-marine pour des motifs commerciaux et athlétiques laisserait à prédire une augmentation correspondante de décès ou d'accidents. Cependant, les dispositions visant à fournir une aide d'urgence sont restreintes au bouche-à-bouche; alors que les compressions cardiaques externes ne peuvent être administrées qu'après que la victime soit transférée sur une surface solide. Cette étude représente une discussion de la technique qui consiste à placer une victime sur la poitrine d'un sauveteur et à enclencher immédiatement un CPR complet sur les lieux. Les ventilations sont administrées au moyen d'un régulateur de plongée légèrement altéré et ajusté à l'usine (Régulateur de ressuscitation d'urgence—E.R.R.). Ces méthodes furent expérimentées sur un mannequin aquatique instrumenté CPR et elles s'avérèrent être en corrélation avec les critères publiés pour accomplir un CPR avec succès.

ressuscitation cardiopulmonaire (CPR)
scuba
sauvetage marin

REFERENCES

1. Jude JR, Kounenhoven WB, Knickerbocker GG. External cardiac resuscitation. Surg Sci 1964;1:59–117.

2. Kounenhoven WB, Jude JR, Knickerbocker GG. Closed-chest cardiac massage. JAMA 1960;173:1064–1067.
3. Pappelbaum S, Lang TW, Bazika V, Bernstein H, Herold G, Corday E. Comparative hemodynamics during open vs. closed-chest cardiac resuscitation. JAMA 1965;193:659–662.
4. Gordon AS. Drowning phenomena in various species. Acta Anesthesiol Scand Suppl 1961;9:81–97.
5. Battaglia JD, Lockhart CH. Drowning and near-drowning. Pediatr Ann 1977;6(4):270–275.
6. National Research Council. Standards for cardiopulmonary resuscitation (CPR) and emergency cardiac care (ECC). JAMA Suppl 1974;227(7):833–868.
7. Definitive therapy in cardiopulmonary resuscitation. (Revised.) New York: AHA, 1971. (EM377A)
8. Schenk H, McAniff, JA. Diving accident survey, 1946–1970, including 503 known fatalities. In: SCUBA Safety Report Series, No. 5. University of Rhode Island, 1977.
9. Malhorta MS, Wright HC. The effects of raised intrapulmonary pressure on the lungs of fresh, unchilled cadavers. J Pathol Bacteriol 1961;82:198–202.
10. Colebatch HJH, Halmagyi DFJ. Lung mechanics and resuscitation after fluid aspiration. J Appl Physiol 1961;16(4):684–696.