International Journal of Cardiology 167 (2013) 1703–1711

Contents lists available at ScienceDirect

International Journal of Cardiology

journal homepage: www.elsevier.com/locate/ijcard

Review

Recommendations for resuscitation after ascent to high altitude and in aircrafts

Athanasios Chalkias [a,1,*], Marios Georgiou [b,1], Bernd Böttiger [c,1], Koenraad G. Monsieurs [d,1], Hildigunnur Svavarsdóttir [e,1], Violetta Raffay [f,1], Nicoletta Iacovidou [a,1], Theodoros Xanthos [a,1]

[a] National and Kapodistrian University of Athens, Medical School, MSc "Cardiopulmonary Resuscitation", Athens, Greece
[b] Nicosia General Hospital, Nicosia, Cyprus
[c] University of Cologne, University Hospital, Department of Anaesthesiology and Intensive Care Medicine, Cologne, Germany
[d] Antwerp University Hospital, Department of Emergency Medicine, Antwerp, Belgium
[e] School of Health Sciences, University of Akureyri, Akureyri, Iceland
[f] Municipal Institute for Emergency Medicine, Novi Sad, Serbia

ARTICLE INFO

Article history:
Received 9 September 2012
Accepted 11 November 2012
Available online 6 December 2012

Keywords:
High altitude
Physiology
Cardiac arrest
Resuscitation

ABSTRACT

Human exposure to high altitude is increasing, through inhabitation of areas of high altitude, expansion of tourism into more remote areas, and air travel exposing passengers to typical altitudes equivalent to 8005 ft (2440 m). With ascent to high altitude, a number of acute and chronic physiological changes occur, influencing all systems of the human body. When considering that cardiac arrest is the second most common cause of death in the mountains and that up to 60% of the elderly have significant heart disease or other health problems, these changes are of particular importance as they may have a significant impact on resuscitation efforts.

Current guidelines for resuscitation lack specific recommendations regarding treatment of cardiac arrest after ascent to high altitude or in aircraft. Therefore, we performed a comprehensive search in PubMed, CINAHL, Cochrane Library, and Scopus databases for studies relevant to resuscitation at high altitude. As no randomized trials evaluating the effects of physiological changes after ascent to high altitude on cardiopulmonary resuscitation were identified, our search was expanded to include all studies addressing important aspects on high altitude physiology which could have a potential impact on the resuscitation of cardiac arrest victims. The aim of this review is to discuss the major physiological changes occurring after ascent to high altitude and their potential effects on cardiopulmonary resuscitation. Based on the available data, specific suggestions are proposed regarding resuscitation at high altitude.

1. Introduction

In 1998, more than 140 million people were living at altitudes above 8202 ft (2500 m) [1]. Not only is the population of high altitude areas increasing, but many people very often visit high altitude regions. It has been estimated that more than 100 million tourists visit mountainous areas worldwide [2]. In addition, there has been lately an increasing trend to advise and encourage those with medical conditions to exercise in mountainous areas [3–6]. However, the commonest way of exposure to high altitude is traveling by airplane, as modern jet airplanes operate in a physical environment that is not survivable for unprotected humans. Federal Aviation Administration regulations in the U.S. mandate that the cabin altitude may not exceed 8000 ft (2438 m) at the maximum operating altitude of the airplane under normal operating conditions [7]. Every year more than 600 million passengers are exposed to a cabin pressure equivalent of that of 8000 ft (2438 m) [8], while at a cruising altitude of 39,000 ft (11,887 m), although more modern aircrafts exposure passengers to slightly lower altitudes such as the Boeing 767 whose cabin is pressurized to an altitude of 6900 ft (2103 m) [9]. In some individuals, however, particularly those with heart or lung disease, symptoms of discomfort may begin at altitudes as low as 4900 ft (1500 m) [10].

With increasing altitude a number of physiological changes occur with hypoxia being the most significant [6]. Atmospheric pressure decreases exponentially with altitude while the oxygen (O_2) fraction remains constant to about 100 km, so the partial pressure of O_2 (PO_2) decreases exponentially with altitude as well. Above 9842 ft (3000 m), the resting O_2 saturation is less than 90%, and it further decreases with increasing altitude. These changes are of great importance, especially when considered that up to 60% of the elderly have clinically significant heart disease or other health problems [6,11].

Cardiac arrest is the second commonest cause of death in the mountains [11]. The risk of cardiac arrest in mountainous areas

* Corresponding author at: National and Kapodistrian University of Athens, Medical School, MSc "Cardiopulmonary Resuscitation", 75 Agiou Thoma Street, 11527, Athens, Greece. Tel.: +30 2104133992; fax: +30 2107462305.
E-mail address: thanoschalkias@yahoo.gr (A. Chalkias).

[1] This author takes responsibility for all aspects of the reliability and freedom from bias of the data presented and their discussed interpretation.

0167-5273/$ – see front matter © 2012 Elsevier Ireland Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ijcard.2012.11.077

increases over the age of 40 [12], while the reported incidence of sudden cardiac death (SCD) is 1–10 per million person days activity in the mountain [12]. In adults, the risk for SCD increases with physical exertion, especially when performing winter sports or attending mass events [5,13,14].

As cardiac arrest and cardiopulmonary resuscitation (CPR) after ascent to high altitude have not been extensively studied, it remains unknown whether resuscitation protocols are as effective as at sea level or if they should be adapted to the relevant physiological derangements. Considering that current guidelines for resuscitation lack specific recommendations regarding treatment of cardiac arrest after ascent to high altitude or in aircraft, the aim of this review is to discuss the major physiological changes occurring at high altitude (above 4900 ft (1500 m)) and to propose recommendations relating to modifications to standard CPR guidelines.

2. Methods

2.1. Search strategy and selection criteria

The literature search was performed using PubMed, CINAHL, Cochrane Library, and Scopus databases from 1950 until April 2011. The details of the search strategy are presented in Table 1. After the initial search by the authors, no randomized trials evaluating the effects of physiological changes after ascent to high altitude on CPR were identified. Therefore, we chose to expand the search to include articles addressing aspects on high altitude physiology, which could have a potential impact on the resuscitation of cardiac arrest victims. Key words were high altitude, physiology, heart arrest, and resuscitation. Articles not available in English and case reports were excluded. The authors completed the literature search and selected by consensus the studies based on title, abstract and complete manuscript. Data extraction was performed twice by the authors and any disagreements were resolved by discussion.

2.2. Results

The search strategy initially identified 155 citations. Assessment of the articles for the stated criteria based on title, abstract or full text resulted in 93 articles being selected for final review (Fig. 1). Most citations retrieved had relevance to high altitude physiology. This systematic review includes 46 articles (animal or human studies and reviews) that examine the physiological changes occurring at high altitude or during hypoxic conditions, 25 articles regarding high altitude illness or diseases, 16 articles regarding cardiac arrest and CPR, and six articles examining the cardiac function and physiology in topics relevant to cardiac arrest.

2.3. Limitations

One limitation is that the database search was restricted to English-language publications. Also, this review combines data from both animal and human studies, some of which include a limited number of participants. Another limitation is that we have used selective reporting in order to present data from studies with small or different populations.

3. Physiological changes at high altitude

The physiological changes during ascent to high altitude occur within minutes and influence all systems of the human body (Table 2). Although not constant, cardiopulmonary performance is affected at 8282–9842 ft (2500–3000 m) where the partial arterial oxygen pressure (PaO_2) is 50–65 mm Hg, compared with 98 mm Hg at sea level (Fig. 2) [15,16]. However, the degree to which changes occur depends on the rate of ascent, the degree of hypoxia, age, medical history, exercise intensity, and level of acclimatization [17]. With acclimatization, some of the physiological changes begin to return towards sea level values, while other may persist for months. In any case, the physiological status is characterized by acute or chronic changes, knowledge of which is essential for medical personnel.

3.1. Respiratory system

The low barometric pressure leads to a decrease in the partial pressure of O_2, impairing its diffusion into lung capillaries and resulting in hyperventilation [2]. The consequent respiratory alkalosis is stabilized within 24–48 h by renal bicarbonate excretion [5], but pH rarely falls to its sea-level value, even after several weeks. Although this enhances the production of 2,3-diphosphoglycerate thus shifting the oxygen–hemoglobin dissociation curve to the right [16], the decrease in PaO_2 is proportional to the fall in barometric pressure with increasing altitude (Table 3). At extreme altitude, the increase in minute volume

Table 1
Search strategy.

Topic	Keywords
High altitude respiratory physiology	Respiratory
	Partial pressure of oxygen
	Hypoxia
	Oxygen–hemoglobin dissociation curve
	Hypoxemia
	Barometric pressure
High altitude autonomic activity	Sympathetic activity
	Sympathetic nervous system
	Parasympathetic nervous system
	Hypoxia, Hypoxemia
	Baroreceptors
	Adrenaline
	Noradrenaline
	Acclimatization
	Adrenaline synthesis
	Noradrenaline synthesis
High altitude cardiovascular physiology	Intravascular volume
	Hypoxia
	Osmolality
	Heart rate
	Cardiac output
	Hemodynamics
	Ischemia
	Arrhythmias, Ventricular fibrillation
	Adrenaline, noradrenaline
High altitude central nervous system physiology	Central nervous system
	Cerebral edema
	Hypoxia
High altitude metabolism	Metabolism
	Glucose, Lactic acid
	Glycogenolysis
	Adenosine triphosphate
	Cellular hypoxia
	Mitochondrial respiration
	Ischemia
	Reactive oxygen species
High altitude hematopoietic physiology	Hematocrit, Hemoglobin
	Erythropoiesis
	Platelets
	Thrombosis
Cardiac arrest	Heart arrest, Cardiac arrest
	Out-of-hospital, pre-hospital, in-hospital
	Emergencies, emergency medical services
	Emergency treatment
	Cardiovascular
	Survival
	Cardiopulmonary resuscitation
	Return of spontaneous circulation
Cardiopulmonary resuscitation	Airway management
	Ventilation
	Oxygen concentration
	Tracheal intubation
	Arterial blood oxygen saturation
	Automatic ventilators
	Hemodynamics
	Chest compressions
	Quality
	Coronary perfusion pressure
	Return of spontaneous circulation
	Defibrillation
	Physiological changes
	Fluid administration
	Venous cannulation
	Intraosseous route
	Hypothermia
	Drugs, drug metabolism
	Rescuer fatigue