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Original Contribution

Serum potassium concentration predicts brain hypoxia on CT after avalanche-induced cardiac arrest

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ABSTRACT

Background: Brain anoxia after complete avalanche burial and cardiac arrest (CA) may occur despite adequate on-site triage.
Purpose: To investigate clinical and biological parameters associated with brain hypoxia in a cohort of avalanche victims with whole body computed tomographic (CT) scan.
Methods: Retrospective study of patients with CA and whole body CT scan following complete avalanche burial admitted in a level-I trauma center.
Main findings: Out of 19 buried patients with whole body CT scan, eight patients had refractory CA and 11 patients had pre-hospital return of spontaneous circulation. Six patients survived at hospital discharge and only two had good neurologic outcome. Twelve patients had signs of brain hypoxia on initial CT scan, defined as brain edema, loss of gray/white matter differentiation and/or hypodensity of basal ganglia. No clinical pre-hospital parameter was associated with brain anoxia. Serum potassium concentration at admission was higher in patients with brain anoxia as compared to patients with normal CT scan: 5.5 (4.1–7.2) mmol/L versus 3.3 (3.0–4.2) mmol/L, respectively ($P < .01$). A threshold of 4.35 mmol/L serum potassium had 100% specificity to predict brain anoxia on brain CT scan.
Conclusions: Serum potassium concentration had good predictive value for brain anoxia after complete avalanche burial. This finding further supports the use of serum potassium concentration for extracorporeal life support insertion at hospital admission in this context.

1. Introduction

Mortality rate after complete avalanche burial is around 52% [1] due to asphyxia, severe trauma and/or deep hypothermia [2,3]. Asphyxia and severe trauma are the leading cause of cardiac arrest (CA) in this context and are associated with poor neurologic outcome [2–5]. Conversely, CA due to accidental hypothermia is rare but may confer ideal condition for successful neurological recovery despite prolonged avalanche burial [6,7]. On-scene triage of avalanche victims with CA aims at identifying patients with isolated accidental hypothermia to be resuscitated until rewarming. Triage algorithms are based upon duration of burial, airway conditions, body core temperature, initial cardiac activity and reported signs of life at extrication [8]. After on-scene triage, updated recommendations for extracorporeal life support (ECLS) relies on body core temperature lower than 30 °C, duration of burial longer than 60 minutes, no severe trauma and serum potassium concentration lower than 8 mmol/L at hospital admission [9]. Despite adequate adherence to algorithms, patients with brain anoxia are still admitted to the Emergency Department (ED), which challenges the usefulness of the applied criteria.

Only limited data are available regarding CT scan findings after complete avalanche burial and mainly focus on traumatic injuries [10,11]. However, signs of brain anoxia on cerebral CT scan would be relevant to further explore the association between clinical/biological parameters and neurological prognosis. Moreover, snow aspiration signs on thoracic CT scan maybe also helpful to test the relevancy of airway pattern assessment in the field. As whole body imaging was performed in

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our center to assess associated injuries and potential brain anoxia in these patients, we decided to test whether CT signs of brain hypoxia were associated with clinical and biological parameters used for triage of avalanche victims with CA [12,13].

2. Methods

We retrospectively studied consecutive avalanche patients admitted in one level-I trauma center (Grenoble University Hospital, Northern French Alps, France) from 2002 to 2014. Patients with the following criteria were finally included: (1) complete avalanche burial, defined as a burial concerning at least head and chest (2) on-scene cardiac arrest, and (3) whole-body CT scan including cerebral, cervical, thoracic, abdominal and pelvic regions. Exclusion criteria were: (1) partial burial (2) no CT scan, and (3) post-mortem CT scan. All these patients were part of a larger cohort used for survival assessment after avalanche induced cardiac arrest [14]. The Regional Institutional Ethics Committee approved the study design (Comité d'Ethique des Centers d'Investigation Clinique de l'inter-région Rhône-Alpes-Auvergne, IRB number 5891, approval on September 1, 2014).

Pre-hospital triage was done on-site by emergency physicians using recommendations for avalanche victims' management edited before 2014 [1,3]. Briefly, following CA, patients were transported to the ED if (1) return of spontaneous circulation (ROSC) was obtained in the field or (2) refractory cardiac arrest by isolated accidental hypothermia was suspected: duration of burial longer than 35 minutes and body core temperature lower than 32 °C with any signs of life reported by witnesses prior to CA, cardiac activity at extrication including ventricular fibrillation, or asystole with patent airway. At hospital admission, ECLS was inserted in patients with serum potassium concentration lower than 12 mmol/L associated with body core temperature (measured by esophageal probe) lower than 32 °C and no obvious signs of trauma.

Clinical and biological data were extracted from the registry of the Trauma System of the Northern French Alps and completed using patients' files if necessary. Pre-hospital data included duration of burial, duration of no flow and low flow, body core temperature measured by esophageal probe, initial cardiac rhythm, signs of life preceding CA, airway patency (air pocket, airway obstruction) and signs of severe trauma. Biological data were collected upon hospital admission on a central line: arterial blood gases, serum potassium concentration, serum lactate concentration, coagulation parameters (activated partial thromboplastin ratio, prothrombin ratio, fibrinogen, platelets count) and hemoglobin level. Injury Severity Score was also recorded. Survival was reported at hospital discharge and neurologic outcome of survivors was assessed using cerebral performance category (CPC) at 3 months.

Whole-body CT scans were done under the supervision of intensivists. The aim of whole-body imaging was to assess associated injuries and potential brain anoxia. CT scans were conducted using Siemens Sensation 16 (Siemens, Erlangen, Germany) or Philips Brilliance 40 and 64 (Philips Medical Systems, Eindhoven, The Netherlands). Whole body CT protocol consisted of the following acquisitions: (1) a non-enhanced encephalic CT scan, (2) a non-enhanced CT scan of the neck, from the base of the skull to the level of the second thoracic vertebra, (3) a contrast-enhanced CT scan of the thorax, abdomen and pelvic regions from the level of the sixth cervical vertebra to the lesser trochanter, (4) a contrast-enhanced scan of the abdomen from the diaphragmatic dome to the lesser trochanter. Arms were placed above the head after the CT scan of the head and neck. Optionally, mainly when a severe cervical traumatism was suspected, a CT angiography of arterial supra-aortic vessels was added. Regarding contrast-medium injection, a 120-mL bolus of iso-osmolar, non-ionic iodinated contrast material [350 mg iodine/ml, Iohexol (Omnipaque 350; GE Healthcare)] followed by a saline flush of 40 mL was injected into an antecubital vein at a flow rate of 4 mL/s. The data acquisition was initiated 6 seconds after 100 Hounsfield Units (HU) attenuation in the descending thoracic aorta. After a further delay of 45 s, the abdominal portal-venous enhanced phase was acquired. For supra-aortic vessel acquisition, an additional injection of 120 mL of the same contrast medium was done, and acquisition was triggered at 75 HU attenuation in ascending aorta.

Three trained radiologists reviewed all whole body CT scans. Involved physicians included one neuroradiologist, one chest radiologist, and one general radiologist. For each patient, radiologists interpreted traumatic and non-traumatic lesions according to the methodology described in Supplemental file no. 1. Brain hypoxia was defined as brain edema, loss of white/gray matter differentiation, and/or hypodensity of basal ganglia. In order to further study radiologic pattern of snow aspiration, and since there is no gold standard for this condition, we proposed defining snow aspiration using the following methodology. First we identified all patients with lung parenchyma abnormalities. We excluded those with isolated gravity-related lung opacities. We checked CT scans of remaining patients for signs of thoracic traumatic injuries, which were defined as fractures of ribs, sternum, clavicles, thoracic vertebrae and the presence of a pneumo- or hemothorax. Traumatic injuries associated with resuscitation were defined as isolated fractures of anterolateral ribs and/or sternum in patients with known cardiac resuscitation [15]. Lung opacities with no associated signs of thoracic trauma (not including traumatic injuries due to resuscitation) were considered as snow aspiration. Traumatic injuries in the whole body were also analyzed using the CT features described in Supplemental file no. 1.

Data were expressed as median and 25th to 75th percentiles. Categorical variables were compared using the Fisher exact test for two-by-two tables and the Freeman–Halton extension for 2×3 tables. Continuous variables were compared using Wilcoxon rank sum test. Multivariate analysis was not conducted given the low number of patients. The properties of serum potassium concentration on admission for brain hypoxia prediction were also tested using receiver operating curve (ROC) analysis. Maximization of the Youden index [16] was used to determine the best threshold. Density function was employed to generate a smooth kernel density ROC curve [17]. 95% confidence intervals of the areas under the curve were yielded using Delong method for the empirical curve [18] and stratified bootstrap from 1000 replicates for the smooth curve [19]. Statistical analysis was done with Stata 12 software. $P < .05$ was declared statically significant.

3. Results

Thirty-nine patients with whole-body imaging were admitted to the ED following avalanche burial within the study period. Only 19 patients met the inclusion criteria for the final analysis (see flow chart in Fig. 1). Pre-hospital characteristics of the study population are shown in Table 1. The median duration time of cardiopulmonary resuscitation was 70 minutes (15–420 minutes). Eight patients were transferred to the ED with refractory CA and 11 patients had pre-hospital ROSC. All patients with refractory CA received ECLS at hospital admission. Eight patients had traumatic injuries but only 2 patients presented Injury Severity Score higher than 15. Detail of injuries is described in Supplemental file no. 2. Biological parameters are reported in Table 2. Six patients (32%) survived at hospital discharge. CPC score was 1 (no disability) for 2 patients, 3 (severe disability) for 1 patient and 4 (vegetative state) for 3 patients. The 2 patients with good neurologic outcome had initial pulseless electrical activity at extrication before refractory CA and ECLS implantation. All patients with initial asystole and refractory CA did not survive ($n = 6$ patients). In the non-survivor patients ($n = 13$ patients), causes of death were brain death for 11 patients (85%) and multiple organ failure for 2 patients (15%).

Out of 19 patients, 12 (63%) patients had signs of brain hypoxia on cerebral imaging. One patient had isolated brain edema whereas 11 patients had diffuse edema associated with loss of gray/white matter differentiation. Univariate analysis between patients with brain hypoxia ($n = 12$ patients) and patients with normal cerebral CT scan ($n = 7$ patients) is presented in Table 3. No clinical prehospital parameter was