THE INFLUENCE OF SNOW PHYSICAL PROPERTIES ON HUMANS BREATHING INTO AN ARTIFICIAL AIR POCKET

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ABSTRACT: Breathing under snow, e.g. while buried by a snow avalanche, is possible in the presence of an air pocket, but limited in time as hypoxia and hypercapnia rapidly develop. It was suspected that the snow physical properties affect the development of hypoxia and hypercapnia. The aim of this study was to evaluate the influence of different snow physical properties on the development of hypoxia and hypercapnia in subjects breathing into an artificial air pocket in snow. Twelve male healthy subjects breathed through an airtight face-mask and 40cm tube into an artificial air pocket of 4L. Every subject performed three tests on different days with varying snow characteristics. Symptoms, gas and cardiovascular parameters were monitored up to 30min. Tests were interrupted at SpO_2<75% or hypercapnia (i.e. $FiCO_2$ >8%) or due to discomfort. Snow density was assessed via standard methods. In eighteen of 36 (50%) tests, subjects completed the full test duration of 30min; tests were terminated due to hypoxemia (SpO_2≤75%) in 13 (36%) cases and due to clinical symptoms in five (14%) cases. Changes of O_2 and CO_2 in the air pocket were correlated with snow density ($p<0.05$), but not with permeability and other related measurements. A rapid decline in O_2 and increase in CO_2 were mainly associated with higher snow densities and led to premature interruption due to critical hypoxia (SpO_2 ≤ 75%). In the low snow density setting a higher frequency of test interruptions than expected occurred, which was linked to clinical symptoms and rapid CO_2 accumulation in the air pocket. In conclusion, snow density seems to have a direct influence on the respiratory gas concentrations and thus test duration of subjects breathing into an artificial air pocket.

KEYWORDS: Snow density, avalanche, respiratory gases.

1. INTRODUCTION

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Asphyxia, i.e. hypoxia and hypercapnia, is the primary cause of death from snow avalanche (Brugger et al., 2009). Approximately 70% of completely buried avalanche victims (i.e. head and chest below the snow) die of asphyxia within 35 minutes (Brugger et al., 2001; Falk et al., 1994). However, several studies have shown that breathing under a snow layer is possible in the presence of a patent airway with or without an air pocket (i.e. any space in front of mouth and nose) (Procter at al., 2016; Roubik et al., 2015; Paal et al., 2012; Brugger et al., 2003; Grissom et al., 2000). Apart from the size of the potential air pocket, development of hypoxeamia in avalanche victims could also depend upon specific snow properties (Brugger et al., 2003; Grissom et al., 2000). The aim of this experimental field study was to elucidate the effects of snow properties on the development of critical levels of hypoxia and hypercapnia in subjects breathing into an artificial air pocket; specifically focusing on the effect of differing snow densities and other snow properties on ventilation and oxygenation in humans. We hypothesized that the speed of the onset of critical physiological levels of hypoxia and hypercapnia would be dependent upon differences in specific snow properties.

2. MATERIALS AND METHODS

This randomized clinical trial was approved by the Institutional Review Board of the General Hospital of Bolzano (No. 0147248) and written informed consent was obtained from the subjects before enrollment in the study.

2.1 Subjects

The sample included 12 healthy Caucasian male volunteers (age: 33.8 ± 7.3 years, weight: 78.2 ± 8.1 kg, height: 179 ± 5.3 cm).

2.2 Design:

The subjects breathed through an airtight face-mask and 40cm tube into an artificial air pocket of

4L. Every subject performed three tests on different days with varying snow characteristics (≤250, 251-350, and >350 kg/m³). Test duration was scheduled for 30 min, but controlled with specific interruption criteria as follow: SpO_2 ≤75%; hypercapnia (i.e. fractional inspired CO_2 >8%); at the subject's request (e.g. due to subjective symptoms like dyspnea, dizziness, and headache), or any other worrying sign of cardiopulmonary or neurologic instability.

2.3 Measurements

i. Clinical parameters

The subjects were continuously observed and monitored by an emergency physician during the test period. Non-invasive variables measured continuously included: blood pressure, 3-lead electrocardiogram, heart rate (HR) and SpO_2 (Monitor HeartStart MRxTM, Philips Medical Systems, Andover, MA), breathing rate (BR), minute respiratory volume (VE) and tidal volume (VT) (OxyconTM mobile device, CareFusion Germany 234 GmbH, Hoechberg, Germany), and main stream end-tidal carbon dioxide ($etCO_2$) (EMMATM Mainstream Capnometer, Masimo, Milan, Italy).

ii. Air pocket parameters

The fractional O_2 and CO_2 concentration in the air pocket was recorded continuously (X-AM 7000, Dräger, Vienna, Austria).

iii. Statistical Analysis

Difference from baseline to maximum value of breathing rate (BR), CO_2-pocket concentration, diastolic blood pressure (DBP), $etCO_2$, pCO_2, HR, systolic blood pressure (SBP), VE and VT, and difference from baseline to minimum value of pO_2, SpO_2 and O_2-pocket concentration were considered as variables for analysis. A general linear model with subject as random factor was performed to investigate correlation of snow physical properties (i.e., density, permeability, snow temperature, coefficient of variation of penetration resistance and standard deviation of penetration resistance) with changes in O_2- and CO_2-pocket concentrations. Tests were two-sided and $p<0.05$ was considered statistically significant. Values are reported as mean ± standard deviation.

3. RESULTS

3.1 Test interruptions and test duration

In total 36 study tests were performed. Specifically, within study tests 18 out of 36 tests lasted 30 min; 13 tests were terminated prematurely due to evident hypoxaemia (peripheral oxygen saturation SpO_2 ≤75%), plus 5 tests were interrupted at the subject's request due to clinical symptoms (dyspnea (n=3), dizziness (n=1), and dyspnea and headache (n=1)).

Time to interruption differed between the three snow density groups ($p=0.002$). Test interruption in the low snow density group was attributable only to clinical symptoms (dyspnea, headache, dizziness) and not due to hypoxia (SpO_2 ≤75%).

3.2 Correlation of physical snow properties with changes in O_2 and CO_2 concentration in the air pocket

Snow density was correlated with O_2-pocket and CO_2-pocket values ($p<0.001$). There was no correlation of either values with permeability ($p>0.05$) or snow temperature ($p>0.05$) or coefficient of variation ($p>0.50$) and SD of penetration resistance ($p>0.05$).

3.3 Individual breathing behavior

There was a progressive decrease in SpO_2 and O_2 pocket, with a parallel increase in VE and CO_2 pocket. The individual ventilatory behavior between the three snow density groups was different and reportedly nonlinear in accordance to snow density, also within the same subject.

4. DISCUSSION AND MAIN CONCLUSION

This study is the first to elucidate in detail the effects of snow properties on ventilation, oxygenation and exhaled CO_2 in subjects breathing into an artificial air pocket.

The study results confirm our hypothesis that the time to the onset of critical levels of hypoxia and hypercapnia is influenced by snow properties. Time to interruption differed, in fact, between the three snow density groups. The concentration of the respiratory gas in the air pocket, plus the consequential impact on ventilatory control was different in accordance to the snow density and also present per subject. In general, the high snow density group demonstrated a rapid decrease in O_2 pocket, plus a concomitant rapid increase in CO_2 pocket that led to a progressive hypoxic milieu and a strong compensative ventilatory response, with a trend to premature interruption due to critical hypoxia (SpO_2 ≤75%). Unexpectedly, the low snow density group showed a similar progression but with different timing and cause of interruption. The subjects of the low snow density group interrupted the test more often than expected, in all cases not due to hypoxia, but to a greater than expected increase in CO_2 and the associated clinical symptoms (dyspnea, headache, dizziness).

CONFLICT OF INTEREST

None of the authors has a conflict of interest.

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