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Evaluation of the ventilatory effects on human subjects in prolonged hip-flexed/head-down restraint position

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ABSTRACT

Background: The restraint chair is a tool used by law enforcement and correction personnel to control aggressive, agitated individuals. When initiating its use, subjects are often placed in a hip-flexed/head-down (HFHD) position to remove handcuffs. Usually, this period of time is less than two minutes but can become more prolonged in particularly agitated patients. Some have proposed this positioning limits ventilation and can result in asphyxia. The aim of this study is to evaluate if a prolonged HFHD restraint position causes significant ventilatory compromise.

Methods: Subjects exercised on a stationary bicycle until they reached 85% of their predicted maximal heart rate. They were then handcuffed with their hands behind their back and placed into a HFHD seated position for five minutes. The primary outcome measurement was maximal voluntary ventilation (MVV). This was measured at baseline, after initial placement into the HFHD position, and after five minutes of being in the position while still maintaining the HFHD position. Baseline measurements were compared with final measurements for statistically significant differences.

Results: We analyzed data for 15 subjects. Subjects had a mean MVV of 165.3 L/min at baseline, 157.8 L/min after initially being placed into the HFHD position, and a mean of 138.7 L/min after 5 min in the position. The mean baseline % predicted MVV was 115%; after 5 min in the HFHD position the mean was 96%. This 19% absolute difference was statistically significant ($p = 0.001$).

Conclusions: In healthy seated male subjects with recent exertion, up to five minutes in a HFHD position results in a small decrease in MVV compared with baseline MVV levels. Even with this decrease, mean MVV levels were still 96% of predicted after five minutes. Though a measurable decrease was found, there was no clinically significant change that would support that this positioning would lead to asphyxia over a five-minute time period.

1. Introduction

One of the ways that law enforcement and corrections officers control aggressive, agitated individuals is to place them in a restraint chair. The process of placing them into a restraint chair often involves the handcuffed subject being placed in a seated position in the chair and pushed forward at the waist in a hip-flexed/head-down (HFHD) position to limit his movements while handcuffs are removed so that the hands can be individually restrained to each arm rest. This typically takes approximately two minutes or less; however, it may take longer if the subject is resisting vigorously or there are difficulties in removing the handcuffs.

There have been anecdotal cases reported of sudden deaths occurring in subjects during, or shortly after, they were placed into a restraint chair using this method. In some cases, the death has been blamed on the use of the restraint chair and its proposed deleterious effect on ventilation, which places the subject at risk of asphyxiation. Asphyxiation that results from body position that limits ventilation enough to cause cardiac arrest has been referred to as “restraint asphyxia” [1]. However, there are a lack of data in the medical literature that placement of individuals into the restraint chair restricts ventilation to the point of clinical significance.

A 2015 systematic review of the restraint chair literature found only one experimental study done on humans [2]. This crossover trial, with 10 subjects, compared maximum voluntary ventilation (MVV) while sitting in a chair compared with being restrained in a restraint chair. There was a small clinically insignificant difference in MVV, but no difference in O2 saturation or end-tidal PCO2 [3].

There is concern that if a suspect is kept in a prolonged HFHD position, ventilation could be significantly affected. In the lone experimental trial of restraint chairs referred to above, subjects were in the HFHD position for less than 1–2 min. This current study is designed to measure

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ventilatory parameters in subjects maintained in the HFHD position for five minutes to simulate prolonged HFHD positioning when placing an individual into a restraint chair.

2. Methods

2.1. Study design

This was a prospective study of healthy male volunteers to evaluate the effect of a HFHD position on vital signs and ventilatory parameters. All subjects underwent a health assessment and completed informed consent before participating in this study. The study was reviewed and approved by the institutional review board. All participants provided written informed consent.

2.2. Study setting and population

This study was performed at an academic medical center using volunteer subjects. Inclusion criteria included male individuals between the ages of 18–55 years and a BMI of 18–30 kg/m^2. Subjects were excluded if there were any positive responses to questions on the Physical Activity Readiness Questionnaire (PAR-Q) or had a history of asthma [4].

2.3. Study protocol

Following completion of the PAR-Q, demographic data were gathered from each subject including age, weight, height, and race. After baseline measurements were obtained in a seated position, including maximal voluntary ventilation (MVV), subjects performed a graded cycling protocol with a stationary bicycle until reaching 85% of predicted maximal heart rate. MVV is reported in L/min, and was calculated using the sprint method where the patient was instructed to breathe as hard and fast as possible for 12 s. The volume of air that is moved over this period is extrapolated to the volume of air that would be moved in 60 s by multiplying it by five [5]. Predicted MVV was generated by the spirometer using gender, age, height, weight, and ethnicity [6]. The manufacturer produced predictive values from normative data [7-12]. Maximal heart rate was defined as 220 minus the subject's age. This was done to simulate physiologic exertion that is typically present in individuals being restrained in the field. Upon reaching goal heart rate, subjects were immediately placed in a chair without arms and placed in a hip-flexed position with the head as close to the knees as possible, and the wrists were handcuffed behind the back using standard forensic handcuffs. (See Fig. 1.) Subjects were maintained in this position for five minutes. In our experience at the jails, placing subjects in the restraint chair takes about 1–2 min, but occasionally a little longer; thus, 5 min seemed a reasonable duration to simulate prolonged attempts at placing subjects in a restraint chair.

Fig. 1. The hip-flexed, head-down (HFHD) position —with the hands cuffed behind the back.

2.4. Measures

Baseline heart rate, blood pressure, tidal volume (TV), and MVV were measured prior to starting the cycling protocol. Blood pressure, TV, and MVV were also recorded at the beginning and end of the 5-min HFHD period. Pulse was monitored throughout the HFHD period. MVV was recorded using the EasyOne Plus Spirometer (Medizintechnik AG, Zurich, Switzerland).

2.5. Data analysis

Baseline vital sign and spirometry measurements were compared with measurements taken at the end of the 5-min HFHD period using a Student's *t*-test. A *p*-value ≤0.05 was considered statistically significant. Data were removed from subjects that did not have a full set of MVV measurements. Analyses were performed using SPSS for Windows, version 26 (SPSS Inc., Chicago, IL).

3. Results

A total of 18 volunteers completed the study. No subject was screened out by exclusion criteria. Data collection was not completed for three subjects: one developed nausea after bicycle exercise and the MVVs could not obtained, while in the other two subjects there was difficulty in positioning in the chair and applying the handcuffs which prevented measurement of the baseline MVV at the beginning of the hip flexion portion. Incomplete data were not included in the final data analysis. 73% of the subjects were Caucasian and 27% were Asian. Other subject characteristics are reported in Table 1.

Table 2 shows the results of the Student's *t*-test that found that mean MVV ($p = 0.001$), mean percent predicted ($p = 0.001$), pulse ($p = 0.000$) and systolic blood pressure ($p = 0.004$) were all statistically significant while diastolic blood pressure ($p = 0.419$) was not. TV was recorded in ten patients. The mean baseline TV was 799 mL (range: 570–1020); after 5 min in the HFHD position, the mean TV was 656 (range: 470–840) mL, a decrease of 18%. This was not statistically significant.

4. Discussion

Law enforcement and corrections officers need safe methods to restrain and maintain aggressively agitated subjects. While restraint positions have been hypothesized to potentially affect ventilation, a recent review concluded that properly executed restraint positions alone, were insufficient to cause asphyxia. In general, the twenty experimental studies done on healthy volunteer subjects occasionally found statistically significant decreases in continuous variables such as FEV1 and FVC, however no clinically significant decreases were found with restraint positions [13].

The absolute difference between the baseline and final mean % predicted MVV was 19% after five minutes in the HFHD position. Though statistically significant, this modest decrease would not have clinically significant effects. After 5 min in the HFHD position, the % predicted

Table 1
Characteristics of study subjects ($n = 15$)

	Mean (SD)	Range
Age (years)	35.7 (13.3)	18–54
Height (m)	1.8 (0.3)	1.2–2.4
Weight (kg)	70.1 (4.0)	63–76
BMI (kg/m2)*	25.1 (3.4)	18–30

BMI = Body Mass Index, *Range for normal classification is 18.5–24.9.

Table 2
Effect of prolonged hip-flexed/head-down position on vital signs, MVV, and tidal volume ($n = 15$)

	Mean (SD)			Baseline vs. Finish	
Measure	Baseline	Start (0 min)	Finish (5 min)	Mean difference (95% CI)	*p*-value
MVV (L/min)	165.3 (35.4)	157.8 (35.0)	138.7 (27.9)	−26.6 (−40.826, −12.521)	0.001
Predicted MVV (%)	115.2 (22.3)	109.1 (24.0)	96.1 (20.6)	−19.1 (−28.30, −9.83)	0.001
SBP (mmHg)	133.5 (20.6)	145.9 (26.0)	149.5 (20.8)	16.0 (6.113, 26.020)	0.004
DBP (mm Hg)	86.1 (6.1)	88.8 (17.5)	89.2 (12.8)	0.40 (−4.839, 10.972)	0.419
Heart Rate (BPM)	82.5 (15.9)	135.8 (23.0)	113.7 (23.9)	−22.1 (17.196, 45.204)	<0.001
Tidal Volume* (mL)	799 (176)	750 (157)	656 (111)	−143 (−0.076, 0.174)	0.402

* Tidal volume was measured on 10 subjects.

MVV, based on patient characteristics was still 96%. Though the HFHD position has minor limitation of maximum air movement, this would not be expected to create any risk for asphyxiation. It should be noted that individuals who are agitated or aggressive are not breathing with ventilatory efforts anywhere near maximum volumes [14].

The mean TV, similar to MVV, decreased 18% after 5 min in the HFHD position; however, it was still 656 mL. Considering that the average dead-space volume is 150 mL, there was still sufficient TV for ventilation in the HFHD position [15].

When considering new findings, it is important to consider existing data. Studies of other in-custody restraint methods have found that positions used to restrain subjects do not cause clinically significant ventilatory or hemodynamic compromise and conclude that other factors are more likely the cause of sudden death in subjects in prone positions [14,16-18]. Thus, our findings are consistent with previous research.

5. Limitations

This study is a pilot study with a small sample size of 15 subjects. In addition, the subjects were healthy volunteers, whereas subjects in field settings may have chronic or unknown medical conditions. Our laboratory model has its limitations and does not necessarily duplicate the sequence of events that may take place in any given field situation. This voluntary nature may not exactly reflect field situations where individuals are often under the influence of drugs or are mentally incapacitated.

Despite these limitations, our study population is similar in respect to the important issue of ventilation. Normative data describing acutely agitated patients is surprisingly sparse, but in randomized trials of sedation agents, subjects are generally in their 30s [19-24]. This suggests cardiopulmonary risk factors are unlikely. (These risk factors are often not reported, but when reported are rare) [19]. Certain intoxicants like alcohol cause hypoventilation; however other common substances like methamphetamine and cocaine do not. It is difficult to determine the exact etiology of agitation in these patients and it is often not reported in trials. One trial of acutely agitated ED patients requiring sedation reported that a quarter of their patients had acute alcohol intoxication [22]. While acute alcohol intoxication is a risk factor hypoventilation, the period where they are acutely agitated and requiring a restraint chair is not the interval where they are at risk for respiratory failure. Lastly, underlying mental illness, commonly associated with acute agitation, is not a risk factor for hypoventilation.

At baseline, the mean MVV was 115% of predicted suggesting selection bias. This does not change our conclusions. The reduction we found in MVV is insufficient to cause asphyxia.

Most cases in which restraint chairs are used in a field setting typically involve male subjects, so we limited this study to male subjects. Males and females generally have similar respiratory physiology, so these findings are probably generalizable to females.

The accuracy of pulse oximeters has not been validated when individuals were in handcuffs and there are reports of false readings because of the handcuffs. Depending on positioning, there can be an artificial lowering of the reading of pulse oximeter because of partial venous outflow obstruction of the hands due to handcuffs. The only choice that would have been valid and reliable to measure oxygen levels would have been an ABG. We felt this would be unnecessarily invasive.

6. Conclusion

In healthy seated male subjects with recent exertion, up to five minutes in a HFHD position results in a small decrease in MVV compared with baseline MVV levels. Mean MVV levels were found to be 96% of predicted after five minutes in HFHD position. Though a measurable decrease was found, there were no clinically significant changes that would support the assertion that this positioning would lead to asphyxia over a five-minute time period.

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Meetings

None.

Credit authorship contribution statement

Richard Childers: Investigation, Writing - original draft, Writing - review & editing, Project administration. **Alexandrea O. Cronin**: Investigation, Formal analysis, Writing - original draft. **Edward M. Castillo**: Investigation, Formal analysis. **Tom Neuman**: Investigation, Conceptualization, Writing - review & editing. **Theodore C. Chan**: Investigation, Conceptualization, Writing - review & editing. **Christopher J. Coyne**: Investigation, Writing - review & editing. **Christian Sloane**: Investigation, Writing - review & editing. **Gary M. Vilke**: Investigation, Conceptualization, Writing - review & editing.

Declaration of Competing Interest

Dr. Neuman, Chan, Sloane, and Vilke are paid legal consultants. The other authors have no conflicts of interest to report.

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