The physiological impact of upper limb position in prone restraint

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Abstract
Deaths occurring during and/or in close proximity to physical restraint have been attributed to positional asphyxia. This study investigated the physiological impact of three recognized prone-restraint positions with participants remaining passive. Position 3 (P3) the supported prone position (SPP) was designed to reduce the extent of pressure on the anterior chest wall (PAC) by bringing the upper limbs underneath the shoulder joint whereas for the other two positions (P1 and P2) the arms were abducted from the torso. Twenty-five adults participated. Forced vital capacity (FVC), expiratory volume in one second (FEV1), heart rate (HR) and oxygen saturations (SpO2) were taken three times in an upright seated position (baseline) and in each prone position. Mean PAC was measured at 102.6 (± 24.3) and 101.4 (± 24.4) mmHg for P1 and P2, respectively; however, in the SPP (P3) the mean PAC pressure reduced to 72.7 (± 16.9) mmHg. All three prone-restraint positions reduced FVC and FEV1 compared with baseline (P<0.001). P1 and P2 where the arms were abducted reduced respiratory measures equally but differed from the SPP position (P<0.001) where PAC was significantly lower. Reductions in FVC from baseline were 16% for P1 and P2, and 11% for the SPP (P3) where PAC was ~28% lower than in P1 and P2. Reductions in FEV1 were similar in all three prone-restraint positions and HR and SpO2 were unaffected. In summary, all prone-restraint positions restrict respiratory function but the risk associated with the position reduces as the PAC reduces.


Introduction
The use of restraint defined as ‘the restriction of a person’s liberty of movement’ (p. 105)1 is an accepted short-term risk management strategy to keep individuals, staff and others from harm when a person exhibits aggressive and violent behaviour.2–4 It is possible that, under certain circumstances, physical restraint may contribute to death5 due to the imposition of a breathing restriction and subsequent cardiac stress (‘positional asphyxia’).6 A recent review of the scientific literature investigating the physiological effects of restraint7 showed that prone restraint imposed a statistically although not clinically significant external restriction to ventilatory capacity as measured by forced vital capacity (FVC) and forced expiratory volume in one second (FEV1). Reductions in ventilatory capacity are proportional to the extent of external restriction imposed by the restraint position. In extreme cases FVC and FEV1 have been reduced by 30–50%.8,9 The restraint position restricted the normal mechanics of ventilation by impeding diaphragmatic downward displacement and thoracic expansion. Respiratory function has not been found to be restricted in upright seated restraint positions.9,10 This study sought to investigate the impact of three prone-restraint techniques on ventilatory and cardiovascular function in order to inform current restraint practices in relation to the short-term application of physical restraint to manage violent behaviour and reduce the risk of harm. The techniques investigated were identical in regards to body position (prone) but differed specifically in relation to the positioning of the upper limbs. The three techniques can be seen in Figure 1. Position 1 (P1) and position 2 (P2) are currently commonly taught and used within UK health, educational and social care settings as well as custodial environments. Position 3 (P3) the ‘supported prone position’ (SPP) was specifically developed with the intention of reducing the extent of respiratory restriction imposed during prone restraint and is used in similar settings as P1 and P2.

Materials and methods
Ethical issues
Ethical approval was granted by the School of Health and Rehabilitation Ethics Committee (Keele University, Newcastle-Under-Lyme, United Kingdom). Participants
signed to give valid consent to take part in the study. No incentives were offered or given to participants to take part in this study.

Participants
Thirty adults with no known health problems were recruited. To be eligible for the study participants had to meet the following criteria: body mass index (BMI) less than 30; free from current musculoskeletal injuries or cardiovascular-respiratory risk factors.

Equipment
Equipment included a Stabilizer™ Pressure Biofeedback unit (PBU), Microlab 3000 spirometer, Norin Onyx pulse oximeter, Cranlea ES-W9032 barometer, SECA 220 stadiometer, SECA 761 weighing scales and Jamar E-Z Read 30 cm Goniometer. All equipment was freely available from the School of Health and Rehabilitation, Keele University, UK.

Conduct of the study
Prior to participant arrival the test area was prepared (20–22°C, humidity <60%). Participants were informed not to consume food, smoke or drink caffeinated beverages two hours prior to testing, or engage in vigorous exercise in the 24 hours prior to testing. Participants were tested individually. On arrival participants’ height, weight and BMI were recorded before being asked to sit and ‘relax’ on a chair for five minutes while the three restraint positions and PBU placement (mid sternum) were demonstrated. Participants were also shown how to exhale into the spirometer (FVC, FEV1) ensuring a good seal around the mouth piece and were familiarized with the verbal instructions they would receive: ‘...breathe in as much air into your lungs as possible, and then force that air out as fast as you can and for as long as you can’. Participants were not to cough during exhalation and if they did the measurement was repeated. During measurement the spirometer was only placed in the participant’s mouth once they had fully inhaled. During expiration all participants were repeatedly encouraged to ‘keep going’ until full exhalation. The first measurements taken were baseline (upright sitting) FVC, FEV1, heart rate (HR) and oxygen saturation (SpO2) which were taken after five minutes of sitting. Participants then lay on the mat in either P1, P2 or P3 the order of which was randomized by triple Latin square to reduce the chance of order effect. After 60 seconds of adopting the allocated prone position measurements of FVC, FEV1, HR and SpO2 were repeated, in addition pressure (mmHg) on the anterior chest wall (PAC) was measured for each participant. To measure PAC the PBU was ‘prepumped’ to 10 mmHg and the pneumatic pressure sensor placed between the participant and the mat at mid sternum (Figure 1d). The PBU was re-set between every single measure. All measures were taken three times (the mean was used for all analysis); 30 seconds were allowed between each spirometry measure.

Figure 1 Prone-restraint positions: (a) Position 1, (b) Position 2 and (c) Position 3 ‘supported prone’ were investigated. Panel (d) shows measurement of anterior chest wall pressure via pressure biofeedback unit.
All three prone-restraint positions involved lying on a 1 cm thick foam mat placed on a firm floor, only upper limb positions differed (Figure 1a–c): P1 – glenohumeral joint abducted 90°, elbows fully extended, palms down; P2 – dorsum of hands placed against lateral chest wall (glenohumeral/elbow joints ~60° abduction and flexion, respectively); and P3 – no abduction of glenohumeral joint, elbows fully flexed, forearms in mid pronation/supination and aligned with acromio-clavicular joints. Measurement using a goniometer ensured correct upper limb positioning.

Statistical analysis

The statistical software package SPSS version 19 (IBM SPSS supplied via Pugh Educational software) was used to analyse the data. Descriptive statistics were used as well as paired T-tests with Bonferroni correction establishing statistical significance at $P < 0.008$ and Pearson’s correlation with statistical significance set at $P < 0.05$.

Results

Thirty participants volunteered. Five were excluded and reasons for exclusion were; one had a BMI >30, one had an exacerbation of asthma and three failed to attend for testing. All 25 participants who consented complied with all study requirements. There were eight women and 17 men (18 Caucasian, 7 non-Caucasian), aged 18–40 years, mean 22 (standard deviation ± 4.3). Height ranged from 1.6 to 1.94 m, mean 1.8 ($±$ 10.7). Weight ranged from 43 to 102 kg, mean 75.2 ($±$ 15.1). BMI ranged from 16.8 to 29.8, mean 24.8 ($±$ 3.2).

Measurement of PAC for each restraint position (Table 1) shows that P1 and P2 resulted in almost equal PAC, whereas SPP (P3) had a PAC ~28% lower than P1 and P2. P1 and P2 were not statistically significantly different, but P1 and P2 were statistically significantly different from P3 ($P < 0.001$). In all the three positions PAC increased in relation to BMI ($r > 0.70$). There was a strong correlation between BMI and the PAC relief afforded by the SPP (P3) ($r = 0.74$; $P < 0.05$ and $r^2 = 0.53$) (Figure 2).

Mean FVC was recorded as 4.55 ($±$ 1.1), 3.8 ($±$ 0.99), 3.8 ($±$ 0.94) and 4.1 ($±$ 1.07) L for upright sitting, P1, P2 and P3, respectively, and mean FEV1 was recorded at 4.1 ($±$ 0.89), 3.4 ($±$ 0.83), 3.4 ($±$ 0.78) and 3.6 ($±$ 0.85) L for upright sitting, P1, P2 and P3, respectively (Figure 3). The decrease in FVC from baseline was 16%, 16% and 11% for P1, P2 and P3, respectively. The decrease in FEV1 from baseline was 16%, 15% and 10% for P1, P2 and P3, respectively. The results of this study demonstrated a statistically significant difference ($P < 0.001$) in FVC and FEV1 between the upright seated position and all prone-restraint positions. FVC and FEV1 did not show a statistical difference between P1 and P2, but P1 and P2 were statistically significantly different from P3 ($P < 0.001$). The FEV1:FVC ratio remained constant at 90% across all four positions. Also unchanged by position were HR with a mean of 70, 73, 70 and 70 beats/min for upright sitting and P1, P2 and P3, respectively. SpO2 also remained unchanged at a mean of 98% for all positions.

Discussion

This study has demonstrated that all three prone-restraint positions investigated imposed a degree of PAC (P1 – 102.6, P2 – 101.4 and P3 – 72.7 mmHg). Of these three

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<th>Position</th>
<th>PAC (mmHg)</th>
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<td>1</td>
<td>102.6 ($±$ 24.3)</td>
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<td>2</td>
<td>101.4 ($±$ 24.4)</td>
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<td>3</td>
<td>72.7 ($±$ 16.9)</td>
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the SPP (P3), which was developed specifically to reduce PAC was found to impose ~28% less PAC than P1 and P2. All three prone-restraint positions imposed a degree of ventilatory restriction as measured by FVC and FEV1 when compared with baseline (\(P < 0.001\)). The ventilatory restriction imposed by the SPP differed from the restriction imposed by P1 and P2 (\(P < 0.001\)). The SPP imposed the least restriction reducing FVC by 11% and FEV1 by 10% whereas P1 and P2 both imposed reductions of 16% in FVC and reductions of 16% and 15%, respectively in FEV1 compared with baseline. FVC and FEV1 did not show a statistical difference between P1 and P2, but P1 and P2 were both statistically significantly different from the SPP (P3) (\(P < 0.001\)). PAC for P1 and P2 was almost identical (\(P > 0.05\)), but P1 and P2 were statistically significantly different from P3 (\(P < 0.001\)). The FEV1:FVC ratio remained constant at 90% across all four positions. Also unchanged by positions were HR with a mean of 70, 73, 70 and 70 beats/min for upright sitting and P1, P2 and P3, respectively. SpO2 also remained unchanged at a mean of 98% for all positions. No differences were noted in HR or SpO2 between the three positions.

This was the first study to investigate the extent of PAC in prone restraint. This was also the first study to investigate ventilatory function for the SPP (P3) and the subsequent physiological effects (FVC, FEV1, HR and SpO2). Previous studies suggested that limb position did not have an additive effect on the restriction imposed by restraint position; this study has shown that limb position can have a reductive effect on the imposed restriction that occurs in prone restraint.

In keeping with current literature this study observed non-clinically significant restrictive reductions in respiratory function for the restraint positions investigated. The lack of clinical significance was supported by unchanged HR and SpO2 measures in all positions compared with baseline. Parkes et al. did, however, observe ‘operationally significant’ reductions in respiratory restriction in restraint positions that limited ventilatory capacity. The differences seen in respiratory restriction between P1, P2 and P3 may only gain clinical significance during ‘real world’ restraint where the physiological demand imposed would require increased respiratory gas exchange to generate a compensatory respiratory alkalosis in response to rising blood acidity. Impediment to the generation of a respiratory alkalosis may ultimately lead to metabolic acidosis and cardiac dysrhythmia; however, such an adverse physiological sequelae is more likely in the presence of other risk factors such as psychosis (delerium/hyper-arousal) and cocaine use, compromised cerebral circulation and/or air entry, psychological stress, psychiatric disorder, psychotropic/anticholinergic medications and aspiration causing asphyxia.

As one would expect those with the greater BMI had a greater PAC measure. Interestingly this current study found that the greater the BMI of a participant the greater was the reduction achieved in PAC in the SPP (P3) compared with P1 and P2. Therefore the PAC reduction achieved in the SPP may gain greater clinical significance as the BMI of restrained individual’s increases, which is of significance since greater BMI has been linked with an increased risk of harm occurring during and/or in close proximity to restraint.

Since retrospective study evidence suggests that pressure on the chest, abdomen and/or body position are the most common cause of death (hypoxia) in cases of non-chemical suffocation, the evidence presented here is applicable to current restraint practice and should be given careful consideration by those utilizing prone restraint as part of a risk reduction strategy for the short-term management of violence. It has been shown that the three prone-restraint techniques investigated imposed differing degrees of PAC and ventilatory restriction. The authors of this study would assert that any reasonable and achievable reduction in the risk of an adverse event occurring during the application of prone restraint, no matter how small, should be adopted and to that end, the SPP (P3) in which the arms are used to reduce the PAC would be favoured as an emergency prone position over positions P1 and P2.

This study applied a robust methodology in order to maintain the studies validity, offering original research into the extent of pressure applied on the anterior chest wall and the impact of that pressure on ventilatory function during the prone-restraint positions. However, the study’s findings are limited as a physiological demand was not imposed on participants prior to or during the measurement process. Future research is now required into risk reduction methods in restraint positions with concurrent struggle against the restraint with blood gas analysis used to measure any differences in physiological impact.

**Conclusion**

This study has shown that all three of the prone-restraint positions tested imposed pressure onto the anterior chest wall and restricted lung function. Of the three prone-restraint positions tested the SPP (P3) imposed the least amount of anterior chest wall pressure and least amount of respiratory restriction. The SPP (P3) where the upper limbs are positioned in order to reduce the PAC would be favoured on the other hand the evidence presented here is applicable to current restraint practice and should be given careful consideration by those utilizing prone restraint as part of a risk reduction strategy for the short-term management of violence. It has been shown that the three prone-restraint techniques investigated imposed differing degrees of PAC and ventilatory restriction. The authors of this study would assert that any reasonable and achievable reduction in the risk of an adverse event occurring during the application of prone restraint, no matter how small, should be adopted and to that end, the SPP (P3) in which the arms are used to reduce the PAC would be favoured as an emergency prone position over positions P1 and P2.

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**References**


