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Review

Restraint physiology: A review of the literature

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ABSTRACT

Law-enforcement often uses forensic restraints to control individuals and often these individuals are placed in positions and with various amounts of weight used to hold them in place. There has been a moderate amount of research performed on humans in this field of study to assess the physiologic impact of the positions and weight on ventilatory and cardiovascular parameters. This review discusses the scientific medical literature on the use of restraints and restraint position including the use of weight force and aggregates the findings in specific physiologic areas, such as impact on blood pressure, heart rate, and ventilatory parameters.

1. Introduction

Restraint is commonly used by law enforcement to control uncooperative subjects that are deemed to pose a significant safety threat to themselves and those around them. There are various types of restraints, including handcuffing, leg shackles, hobbling, maximal restraint to name a few, but restraint use and body positioning has proved to be controversial over the years with numerous reports of injury and death in those detained. By nature, many restrained detainees exhibit some form of agitation prior to a potentially harmful incident. Physical struggles, drug intoxications, or pre-existing health conditions can all be in play in the event of a tragic outcome. In attempts to explain these adverse outcomes, a growing body of research has emerged over the years analyzing the physiologic effects of various restraint methods. This literature review aims to summarize these findings and offer a future direction of research to protect both those who are restrained and those responsible for restraining.

Research into the safety of positional restraint emerged in the early 1980s with the examination of "choke holds" leading to their banning by the majority of law enforcement.[1,2] Much of the research thereafter focused on the "hog-tie" or "hobble" restraint, also referred to as the prone maximal restraint position (PMRP). In this variation of restraint, the subject is placed in the prone position with arms handcuffed and ankles bound. The knees are then flexed, and the ankles secured to the handcuffs. It had been postulated that positional restraint could in some way affect an individual's ability to properly ventilate. Some have considered that such positioning could obstruct the upper airway or restrict the motion of the chest wall, diaphragm, or abdomen. This idea, coined "positional asphyxia" was first used by Bell et al. who examined 30 cases of asphyxia-related death in a nine-year period in Broward, FL.[3] Their study found that most often, the deceased individuals were found in positions that obstructed the upper airway. Of the thirty, four cases were reportedly found in positions that restricted chest and diaphragm movement, suggesting perhaps the cause of death could have been from hypoventilatory respiratory failure. No other significant contributors to death were found in these subjects.

Additionally, several case reports have been published over the years implicating the "hobble" restraint as a cause of death in restrained individuals.[4–7] All of the authors of these reports postulated that positional asphyxia in some way played a role in the death of these individuals. It is notable however that the vast majority of these subjects were either agitated, violent, or under the influence of alcohol, cocaine, or other substances. Without sufficient data to support restraint as a primary cause of death, many investigators were concerned about these confounding factors playing a role. They argued that restraint alone may not be sufficient to cause death and it is instead factors such as delirium, agitation, fatigue, drugs, and alcohol that lead to compromise. In the time since, efforts have been made to grow the database, expanding our clinical knowledge of the physiologic effects of restraint on the human body. A comprehensive list of published prospective research is included in Table 1.

1.1. Ventilatory effects of restraint

One of the first studies supporting the theory of positional asphyxia was published by Reay et al., in 1988.[8] The study examined the recovery

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rate of oxygen saturation and heart rate in subjects placed in the hogtie position after exercise. The authors witnessed an increased recovery time across both parameters in the hogtie position compared to sitting, concluding that positional restraint may indeed restrict cardiorespiratory function and should be considered as a cause of death when implicated. The study was met with controversy. Critics expressed concern about the use of transcutaneous pulse oximetry and its known inaccuracy, as well as the lack of spirometry to measure ventilatory function. Most notably however, authors pointed to the fact that Reay observed an initial decrease in oxygen saturation during exercise. This finding contradicted the fundamental understanding of exercise physiology in which one would expect to see an increase in saturation during exercise.[9,10] It was also noted that while in the hogtie position, the subjects in Reay's study actually had an increase in their oxygen saturations back to normal levels. In a follow up study, Schmidt et al. attempted to replicate Reay's work, this time finding no significant differences in recovery rate of identically tested parameters.[11] Furthermore, desaturation was not observed during exercise as previously found. Many investigators have found fault with the early work of Reay, despite the study's popularity in being the first to support the theory of positional asphyxia. Efforts were made in the following years to develop a better understanding of respiratory physiology under restraint.

The effects of positioning on ventilatory function in healthy subjects were not previously well-understood. Common suggestions of potential phenomena included increased intra-abdominal pressure in the supine position restricting lung expansion, anterior rib pressure restricting lung expansion in the prone position, and positioning affecting ventilation/perfusion zones within the lung itself. In 2000, Vilke examined PFT's in

Table 1
Prospective studies on restraint physiology.

Paper Title	Authors	Number of Subjects Enrolled	Notes	Positions compared
The Physiological Impact of Upper Limb Position in Prone Restraint (2012)	Barnett	25	The study demonstrated a decline in spirometry performance across several variations of prone positioning, although the values were not considered clinically relevant.	Variations on prone positioning
The Effect of Simulated Restraint in the Prone Position on Cardiorespiratory Function Following Exercise in Humans (2000)	Cary	12	Subjects were exercised to 85% and parameters measured during recovery. Restraint was simulated with a 75 kg place on the back in the prone position. **Want to double check statistical significance here.**	Prone
Weight Force During Prone Restraint and Respiratory Function (2004)	Chan	10	Subjects were placed in the PRMP with weights of 25 kg and 50 kg added to their back.	PRMP ± weight versus sitting
Restraint Position and Positional Asphyxia (1997)	Chan	15	Measured pulmonary parameters in sitting, prone, supine, and restraint positions before and after exercise.	PRMP versus prone
The Effect of Oleoresin Capsicum "Pepper" Spray Inhalation on Respiratory Function (2002)	Chan	34	Subjects were exposed to capsicum spray in the PRMP.	PRMP versus sitting ± Capiscum spray
Effect of Position and Weight Force on Inferior Vena Cava Diameter – Implications for Arrest-Related Death (2011)	Ho	24	Subjects were placed in the prone position with added weight forces of 45 kg and 67 kg.	Prone
Does Weight Force Application to the Lower Torso Have an Influence on Inferior Vena Cava and Cardiovascular Parameters? (2008)	Krauskopf	6	Subjects were in the prone position with added weight forces of 5, 15, and 25 kg to the lower torso.	Prone
The Cardiopulmonary Effects of Restraints on People with COPD (2005)	Merideth	5	Although the study found no significant differences in the tested parameters, 3 subjects were excluded as they experienced clinical decline while prone.	Prone
Effect of Wrist Restraint on Maximal Exercise Capacity in Healthy Volunteers (2005)	Merideth	12	Subjects were exercised on a bicycle and randomized to hand restraints in front or behind their back.	On bicycle with hands restrained behind back
Ventilatory and Metabolic Demands During Aggressive Physical Restraint in Healthy Adults (2007)	Michalewicz	30/27	Part 1. Subjects were placed in the PRMP with weights of up to 90.1 or 120.3 kg added to their back. Part 2. Subjects were exercised to 85% and parameters measured during recovery.	PRMP versus prone or seated
Sudden Death During Restraint: Do Some Positions Affect Lung Function? (2008)	Parkes	15	Subjects were placed in the "flexed restraint" position with weight added to the torso.	Prone and "flexed restraint"
Effects of Positional Restraint on Oxygen Saturation and Heart Rate Following Exercise (1988)	Raey	10	Subjects were exercised with parameters measured during recovery in the restraint position.	PRMP versus sitting
Cardiopulmonary Consequences to Hobble Restraint (1997)	Roeggla	6	Subjects were placed in either an upright or prone hobble restraint with significant results corresponding to the prone group. **Looks like spirometry results likely clinically irrelevant here.**	Prone hobble versus upright hobble
The Effect of the Prone Maximal Restraint Position with and without Weight Force on Cardiac Output and Other Hemodynamic Measures (2013)	Savaser	25	Subjects were placed in various positions with 50 kg and 100 kg weights added to their backs while in the PRMP. There was a small significant decease in CI in the 50 kg PRMP verus supine position.	PRMP ± weight versus prone and sitting
The Effects of Positional Restraint on Heart Rate and Oxygen Saturation (1999)	Schmidt	18 (Part 1)	Subjects were exercised on a bicycle before parameters were measured during recovery in the restraint position. **There were statistical changes in O2 sat but thought to be very small and likely not clinically relevant*.**	Hog tie (PMRP) versus seated
The Effects of Positional Restraint on Heart Rate and Oxygen Saturation (1999)	Schmidt	16 (Part 2)	Subjects sprinted and then underwent a simulated struggle before being placed in a modified hogtie position.	Modified hog tie (PMRP) versus seated
Evaluation of the ventilatory Effects of the Prone Maximum Restraint (PMR) Position on Obese Human Subjects (2014)	Sloane	10	Ventilatory parameters were measured in subjects with a BMI over 30 in the PRMP.	PRMP versus prone or seated
Spirometry in Normal Subjects in Sitting, Prone, and Supine Positions (2000)	Vilke	20	Spirometry measurements were compared across subjects in prone, sitting, and supine positions.	Prone versus supine and sitting
Evaluation of the Ventilatory Effects of a Restraint Chair on Human Subjects (2009)	Vilke	10	Subjects were exercised to 85% and parameters measured during recovery in a restraint chair.	Restraint chair versus normal chair

prone, supine, and sitting subjects. He found statistically significant decreases in FVC, FEV1, and MVV, although the results were not shown to be clinically significant.[12]

In 1997, Chan et al. were one of the first groups to measure ventilatory function by spirometry in restrained individuals.[13] Their study, which examined PFTs in sitting, prone, supine, and restraint positioning before and after exercise found statistically significant declines in FVC, FEV1, and MVV when subjects were placed in the PMRP. Although subjects did develop a restrictive lung pattern in the restraint position, the changes were not considered to be clinically relevant and there was no evidence of hypoxemia or hypercarbia demonstrated on arterial blood gas measurements. In a similar study, Roegella et al. showed decreased FVC and FEV1 in patients in the prone hobble restraint versus sitting hobble restraint.[14] End-tidal CO2 were mildly increased, but oxygen saturation remained unchanged. Despite the statistically significant changes, the values are not considered to be clinically relevant.

Other investigators have sought to replicate this previous work with attention to additional variables in attempts to closer simulate real-life restraint. It has been suggested that positional restraint alone is not enough to cause ventilatory compromise and it is often additional factors that contribute to mortality. One common theory is that the act of restraint can add a weight force to a subject that significantly restricts ventilation. Barnett et al. examined this idea by measuring the anterior chest pressure caused by prone positioning and the extent to which it affected ventilation.[15] The study compared standard prone positioning to a modified "supported prone" position which was hypothesized to reduce pressure on the anterior chest wall. The study showed that all positions exerted some degree of pressure, although less so in the modified position. FVC and FEV1 were also decreased across all positions, less so in the modified position. Although the positions did cause restrictive reductions in lung function, they were not noted to be clinically significant.

In 2000, Cary et al. were one of the first groups to examine the effects of added weight during restraint.[16] Their study exercised subjects to 85% of predicted maximum heart rate and measured cardiopulmonary parameters during recovery at 2 and 3 min in the sitting, prone, and "prone with restricted thoracoabdominal movement" position. Restraint in this case was simulated by prone positioning with 75 kg distributed evenly over the subject's back. Interestingly, the study showed a statistically significant increase in end-tidal CO2 and decreases in mean blood pressure and heart rate in the prone position compared with the seated position, but no significant differences in the restraint position. FVC, FEV1, and MVV also declined but were not considered clinically relevant. Chan et al. later expanded on this study, applying it to the PMRP.[17] Spirometry parameters were measured in subjects in the PMRP with 25 lbs and 50lbs placed on the back. Like previous studies, Chan demonstrated a restrictive lung pattern in the PMRP but without significant changes in FVC or FEV1 with the addition of a weight force. These changes were also not clinically significant, with no evidence of hypoxia or hypercarbia.

Arguing that 50lb was not likely the maximum amount of force that could be generated by an officer in the field, Michalewicz measured the MVV of subjects in the PMRP with up to 102.3 kg placed on the back.[18] Following in a similar pattern to experiments prior, the study showed statistically, but not clinically significant decreases in MVV. Similarly, Parkes et al. measured changes in FVC and FEV1 in prone subjects with an applied weight force of two adults lying on either side of the torso.[19] The study demonstrated a restrictive lung pattern with significant decreases in FVC and FEV1. Given this decrease in ventilatory capacity, the authors argued that prone restraint positioning could be considered a risk factor for sudden death, particularly with an applied weight force, but were unable to draw conclusions about clinical significance. The study was limited in that oxygen saturation and end-tidal CO2 were not measured, thus increasing the challenge to determining clinical relevance.

Others have suggested that rib fractures could be used as a marker for chest compression asphyxia deaths.[20] Kroll et al. expanded this idea and postulated that a force-generated flail chest could be sufficient enough for death.[21] While previous research focused on velocity-generated flail chest, the authors attempted to develop a model to predict the compression force needed to create flail chest which would be more applicable to a forensic scenario. Using a series of models, the authors predicted that a static force of 2550 ± 250 N (260 ± 26 kg) would be sufficient to cause a flail chest, which was defined as bilateral fractures of ribs #3–5. In application to the theory of positional asphyxia, it would seem that a significant force would need to be applied to a subject to induce a respiratory compromising flail chest. The model was only based on male subjects in the supine position, although the authors suggested that the prone position may be able to handle even greater weights due to the hinging of the costophrenic angle.

Kroll et al. later investigated the force generated by typical restraint and whether it could be correlated to the weight of the restrainer.[22] The study examined a variety of prone restraint techniques and measured the force each one generated on a training mannequin. They compared techniques where either a single knee or both knees were placed on the subject's back, finding that the double knee technique transferred the greatest amount of force. The study interestingly found no correlation overall between a generated force and the weight of the person applying it, although the authors did see a 24% transference in the double-knee technique. They calculated a maximum force of 73 kg with the double knee technique that was judged to be well within the 260 ± 26 kg range they had previously set for a threshold of flail chest. Furthermore, this value was less than the 102 kg shown by Michalewicz to not clinically affect ventilatory function.[18] The authors suggested that greater force may be applied by more aggressive restrainers but added that a struggling subject could limit the degree to which that force could be applied.

Further theories to the effects of positional restraint on ventilation have been proposed. Reay et al. suggested that restraining a subject's hands behind the back could hyperextend the shoulders and reduce chest wall expansion, leading to ventilatory compromise.[4] Meredith tested this hypothesis by measuring heart rate and lactate in subjects on an exercise bike with hands restrained behind their backs.[23] No statistically significant differences were found in either lactate or heart rate across groups who reached maximal exertion. The study admitted that maximally exercising patients in the prone position is impossible, limiting their ability to examine any further positions besides simply restraining the hands behind the back. More research would be needed to evaluate the effect of prone positioning in maximally exercising subjects, not just those who are recovering.

All of these studies are limited by not being able to assess the effects that drugs, alcohol, and other substances have during restraint nor the effects these substances have on the individuals.

1.2. Cardiac effects of restraint

Investigators have also postulated that death from positional restraint could be mediated by cardiovascular parameters. In particular, it has been theorized that increased intraabdominal pressure could reduce venous return leading to cardiopulmonary compromise. Roegella's previously mentioned 1997 paper also examined the cardiac function of subjects in the hobble restraint.[14] The study showed significant decreases in cardiac output, systolic blood pressure, and heart rate in the prone hobble vs. prone sitting position. The investigators hypothesized that the decreases in blood pressure and cardiac output could be attributed to decreased venous return from an increase in intrathoracic pressure. However, it is important to note that only 6 subjects were included in the trial. Furthermore, cardiac parameters were measured using a non-invasive Porta-Pres with cardiac output inferred by pulse curve analysis.

In 2008, Krauskopf examined IVC diameter via ultrasound in prone subjects with weight up to 25 kg placed on the lower torso.[24] The study showed that weight force applied to the lower torso leads to significant

decreases in diameter and maximum blood flow in the IVC and minimal decreases in cardiac index and output. Other cardiac parameters were not affected, and the authors suggested that increased weight, which would be more likely to be encountered during an active restraint, could lead to more clinically significant outcomes. Ho et al. performed a similar experiment in 2011 with weights of 45 kg and 67 kg applied to the upper torso of prone patients.[25] The study showed significant decreases in IVC diameter with addition of weight, but no changes in vital signs. The authors inferred that cardiac output may be decreased, presuming decreased venous return, but did not measure these values directly.

It is important to note that the degree to which cardiac output was accurate in each of these studies is somewhat limited. Ho used IVC diameter as a marker of cardiac filling to infer cardiac output while Krauskopf used impedance cardiography, which has known variability. In 2013, Savaser et al. argued the previous work of Roegella, Krauskopf, and Ho was limited by study design: citing poor O2 measurement, the limitations of impedance cardiography, and poor randomization with regards to positioning.[26] Savaser's study examined cardiac output of subjects in the PMRP with a weight force applied. Restraint positions were randomized and left ventricular outflow tract (LVOT) diameter was used to calculate cardiac output. The study showed no significant differences in cardiac output in the PMRP with 50lbs and 100 lbs of weight added to the back compared to prone and supine positioning. There was a small significant difference in cardiac index between the supine and PMRP with 50lbs. Heart rate, mean arterial pressure, and oxygen saturation remained normal in all positions, supporting that there are no significant cardiac effects of restraint in otherwise healthy individuals.

All of these studies are limited by not being able to assess the effects that drugs, alcohol, and other substances have during restraint nor the effects these substances have on the individuals.

1.3. Restraint under real-world scenarios

The predominant criticism surrounding the current research on positional asphyxia is that it is performed on healthy subjects, usually at rest. Critics argue that in a real-world restraint scenario involving injury or death, subjects are likely to be under a significant amount of physiological and psychological stress. It is thought that the physical altercation involved in such scenarios may lead to increased cardiovascular and ventilatory demand that becomes further compromised by the introduction of positional restraint. Moreover, those with preexisting health conditions may be at a higher risk of mortality due to complications of restraint.

Some authors have attempted to address these concerns by conducting studies with added variables to better simulate real-world scenarios. In an additional second part of the 1999 study, Schmidt measured the rate of oxygen saturation recovery in restrained subjects after a simulated struggle, finding no significant changes.[11]

It also has been suggested that under situations of high physical exertion, oxygen consumption may exceed ventilatory capacity in some individuals.[27] In another component of their 2007 paper, Michalewicz measured oxygen consumption (VO2) and minute ventilation (Ve) in subjects in the PMRP after a simulated struggle.[18] The values found were less than 42% of the peak values generated during a baseline maximum exertion treadmill test. The study thus concluded that factors other than ventilatory failure likely lead to fatality in restraint incidents. The authors did concede that the simulated struggle was on a voluntary basis in healthy subjects not under the influence of illicit substances but were confident that their increased heart rate reflected adequate exertion from which to draw conclusions.

Obesity has also been a variable of concern. While previous studies had shown no cardiac or ventilatory changes in healthy subjects in the PMRP, Sloane et al. postulated that perhaps increased abdominal mass could lead to a restrictive lung pattern in the restraint position.[28] The study examined 10 adult subjects with a BMI greater than 30. Ve, end-tidal CO2, and oxygen saturation were measured in subjects in the PMRP while they recovered after reaching 85% of maximum heart rate on an exercise bike. The study found no significant changes in Ve, oxygen saturation, or end-tidal CO2 between the three positions and thus no clinically significant differences. There were some minor changes in heart rate and end-tidal CO2 at the 15-min mark, but these were not statistically significant. The authors admitted that despite subjects all being over a BMI of 30, abdominal girth was not measured.

Many positional restraint experiments exclusively include healthy subjects without preexisting health conditions. In 2004, Meredith et al. measured the effects of prone positioning on subjects with a history of COPD.[29] Interestingly, of the eight subjects that were recruited to the study, only five were able to tolerate the prone position. Three subjects could not tolerate the prone position for 10 min and were removed from the study due to breathlessness, wheezing, and desaturation, respectively. Of the five that did complete the study, there were no significant changes in FVC or FEV1 noted in the prone position. Despite its small sample size, the study concluded that the response to restraint in COPD patients is highly individual and invited future research into subject.

With reference to the current COVID-19 pandemic, some have drawn attention to the medical management of these patients and how it relates to the physiology of prone restraint. Recent recommendations for the management of ventilated COVID-19 patients with moderate to severe ARDS have suggested the implementation of prone positioning.[30] Prone positioning has been shown to improve ventilation through a number of ways, namely by the reduction of the ventral-dorsal transpulmonary difference and through improved perfusion to the dependent portions of the lung. It has been suggested by some that these physiologic benefits add further evidence to the contradiction of positional asphyxia, arguing that prone positioning at the very least is not detrimental from a V/Q perspective.

In a unique study, Chan et al. hypothesized that pepper spray could worsen ventilatory function through laryngospasm, upper airway restriction, edema, or bronchoconstriction.[31] This potential compromise in ventilatory function could in theory lead to clinical decline when in the PMRP, which had previously been shown to cause a restrictive lung pattern. Thirty-four healthy adult subjects were tested with initial measurements showing the previously demonstrated restrictive pattern in the PMRP. Subjects were then exposed to a spray of oleoresin capsaicin pepper spray under a hood which they inhaled for 5 s. Repeat spirometry after exposure showed no significant changes in FEV1 or FVC, with no evidence of hypoxia or hypercarbia. The authors did add that subjects were not under any form of exertion during the trial which could have provided a more realistic scenario. Furthermore, the spray was inhaled in a hood rather than sprayed directly on the face as it was thought such a method would ensure more interaction with the pulmonary system. The study did not exclude patients with pre-existing conditions and actually included a small number with asthma, smoking history, or other lung disease. Although there were no significant differences in results among this population, the sample size was too small to draw conclusions from and was thought to be an interesting avenue to pursue in the future.

Other areas of research have investigated alternative forms of positional restraint such as restraint chairs which have been implicated in "mechanical asphyxia" related deaths. A restraint chair is a device used by law enforcement to secure an agitated or violent subject. The subject is leaned slightly back in the chair with their hands secured in front of them on arm rests and their feet secured near the base. In Vilke's 2009 study, subjects were exercised 85% of maximum predicted heart rate before being immediately placed into the restraint chair.[32] Post-exercise measurements of MVV, oxygen saturation, and end-tidal CO2 were compared with post-exercise subjects sitting in a normal chair. The study found a statistically but not clinically significant decrease in MVV and no differences in oxygenation or ventilation in the restraint chair group.

Other research has been performed in a retrospective epidemiologic manner to evaluate the impact of restraint and prone positioning on

individual subject outcome. Four studies evaluated real world police use of force events that resulted in prone positioning.[33-36] Hall et al. reviewed restraint and police use of force events and in 1255 subjects and reported that 42.8% were left in a prone position and none of the subjects died.[33] Hall et al. subsequently reviewed restraint and police use of force events and in 4828 use of force events, with over 2000 of the subjects were restrained in a prone position. There was only one death in this study population, and that subject was not in a prone position.[34] Ross and Hazlett reported that in 110,173 arrests, 1085 incidents resulted in prone positioning of the subject. In this study population, they reported no deaths.[35] Lasoff et al. reported that in 2431 use of force incidents, 63.1% ended up being placed in a prone restraint position and no fatalities were noted.[36]

2. Conclusion

In summary, a total of twenty experimental studies were analyzed in this literature review. To better summarize the cumulative findings of this research, we elected to look at parameters in isolation across experiments:

Of the examined papers, fourteen experiments measured oxygen saturation as an outcome. All fourteen demonstrated no clinically significant drops in oxygen saturation in the restraint position. Three studies analyzed effects with weight applied to a subject.

End-tidal CO2 was measured in seven studies, all of which found no clinically relevant effects. Weight was added to subjects in two of these seven papers.

Ventilatory function was measured by FEV1 and FVC in nine studies, three of which applied weight to subjects. All experiments found statistically significant decreases in FEV1 and FVC. Despite the emergence of what authors considered to be a restrictive pattern, FEV1 and FVC remained within clinically normal range in all studies. Additionally, MVV was measured in five studies, also with statistically but not clinically relevant changes.

Twelve experiments measured heart rate as an outcome of positional restraint, four of which applied weight to subjects. All twelve of these studies found no clinically significant increases in heart rate.

Systolic blood pressure was measured in five studies, of which four applied weight to subjects. No clinically significant effects on systolic blood pressure were found.

Cardiac output was measured in three studies, with two applying weight to subjects.[14,24,26] Two of these studies found no clinically significant changes in cardiac output. Roegella did demonstrate a significant decrease in cardiac output although we previously drew attention to the paper's small sample size and inaccurate inferences of cardiac output.

Overall, our review of the literature did not demonstrate positional restraint to be sufficient to cause ventilatory or cardiac failure. Measurements of oxygen saturation, end-tidal CO2, as well as spirometry did not show clinically significant adverse outcomes. Based on spirometry, it's clear that the act of restraint (particularly with a weight force) does affect lung function through a restrictive pattern. However, with lack of clinically significant changes in spirometry, it is hard to conclude that restraint alone would be enough to cause asphyxia or ventilatory arrest. With regards to cardiac function, no significant changes were found in heart rate or systolic blood pressure. It would appear that while weight force in the restraint position is sufficient to lower IVC diameter, changes in cardiac output have only been shown by inference and in another study found to be problematic. And none of these studies demonstrated any changes in the subject's ability to maintain blood pressure.

In summary, these findings lend further credence to the theory that factors outside of restraint alone lead to morbidity and mortality. Many of these experiments were performed on healthy, adult subjects without significant medical histories. While some studies did simulate the physical struggle of restraint, it is hard to guarantee this situation would be similar to one encountered in the real world as it is difficult to assess the effects that drugs, alcohol, and other substances have during restraint. However, these studies impact the medical profession, law enforcement administrators with policy and training decisions, and the officer in the field when deciding to actually apply the prone restraint technique with combative individuals. Based on the available published research, the data are not sufficient to conclude that positional restraint alone is enough to cause ventilatory or cardiac compromise in healthy, adult subjects.

Declaration of competing interest

Gary Vilke is a paid legal consultants. There are no other conflicts of interest to report.

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