Positional, Compression, and Restraint Asphyxia: A Brief Review

Technical Report · February 2017

DOI: 10.13140/RG.2.2.29179.31527

1 author:

Mark W Kroll
University of Minnesota Twin Cities
244 PUBLICATIONS **2,149** CITATIONS

Positional, Compression, and Restraint Asphyxia: A Brief Review

Mark Kroll, PhD, FAIMBE
Feb 2017

Compression Asphyxia

Compression asphyxia is a real phenomenon and it has resulted in many deaths. This is not controversial. What is controversial and largely debunked now, is the mis-application of this to arrest-related and custodial deaths. In the USA alone there are about 800 cases of arrest-related-death annually and in some cases the subject expired after law enforcement officers used short-term controlling pressure on the back of the chest during handcuffing.[1] Hence, there has been debate about the potential for law enforcement officers to be able to cause fatal compression asphyxia with their body weights.[2-12] This is sometimes incorrectly referred to as "restraint" or "positional" asphyxia due to the restraints of the wrists and ankles along with the prone position in the law-enforcement scenario.

Compression or crush asphyxia has caused death from soft-drink (soda) vending machine tipping, building collapse, vehicle accidents, crowd collapse, and trench cave-ins.[13-23] True compression asphyxia, has been differentiated as "a form of suffocation where respiration is prevented by external pressure on the body."[16,24]

Published research has found no evidence of compression asphyxia in hogtied individuals with a static mass up to 102 kg (225 lbs) on the back.[25] However, numerous deaths from falling soda machines have been reported. [17-20]

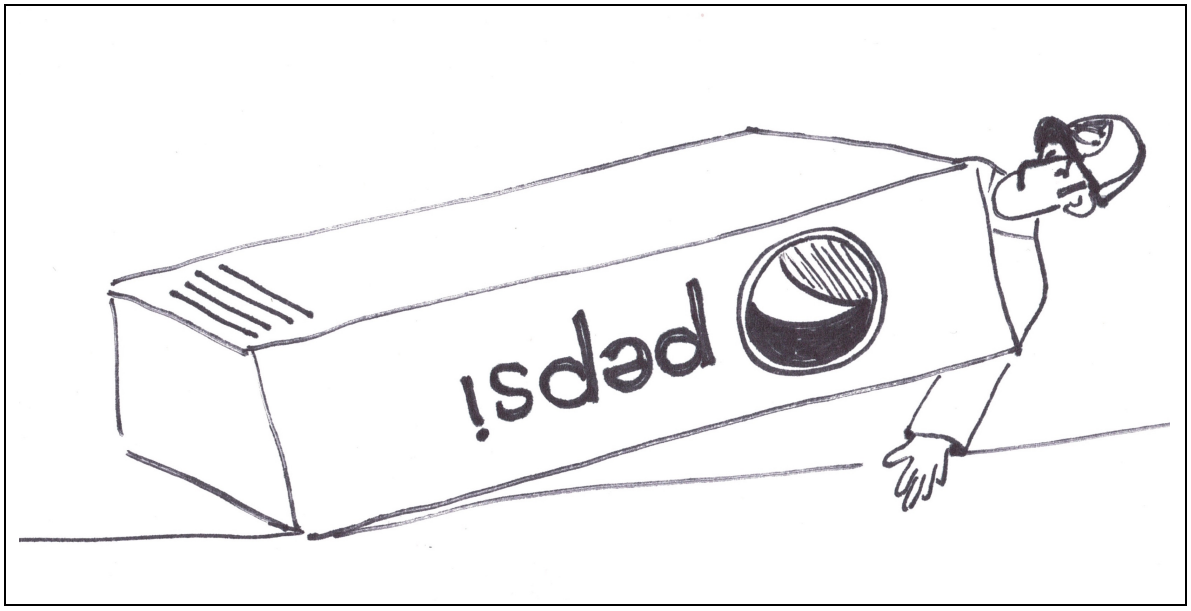

Figure 1. True compression deaths typically involve broken ribs and weights over 1000 lb.

Since a fully-loaded soda vending machine weighs up to 500 kg (1100 lbs), with most of the mass in the top, these deaths establish that an impact (falling) load of 500 kg can kill an adult human.

Most of the published fatal chest compression cases involve the mass of

a car or tractor (typically > 1000 kg) compressing the torso and hence they set a high upper bound on the mass required for ribcage failure. [16] [26] Conversely, cases of survival under a motor vehicle do not appear to have the full vehicle weight on the subject. For example, Shamblin reported a case of a farmer pinned under the steering wheel of an overturned tractor; he had several rib fractures but only on the right side and survived. [13]

Vega and Adams have suggested the use of rib fractures as a marker for torso compression.[27] In the setting of short-duration chest compression, such as that typically encountered during handcuffing, fatal compression asphyxia, due to ineffective breathing, probably requires a flail chest injury since diaphragmatic breathing can support life even with the chest restricted. [28-31] We recognize that compression asphyxia can kill even with no ribs fractures. However, that appears to require a longer-term compression or the rapid application of heavy weight to the chest.[15,26,32]

Figure 2. The human chest can handle a surprising amount of weight.

The US National Football League injury statistics were recently published.[33] Counting practices and games from 2000 to 2010 there were a total of 31,338 injuries that resulted in players leaving a game or practice. Minor sprains, bruises and other trivial injuries were not included. There were a total of 2 rib injuries. These 2 rib injuries were more likely bruises and not fractures. Rib injuries, including possible fractures, that did not preclude participation in training or competition were also not included. Since the American (and Australian) version of football often involves large body-piles, these data suggest that it is very difficult to generate significant rib injuries from the weight of other humans. Granted, professional football players are in excellent physical condition with strong musculo-skeletal systems. On the other

hand, the other players applying the weight tend to be very heavy. Rib fractures in football appear to most commonly result from localized impacts rather than diffuse compression.

Cadaver car-safety tests of steering-wheel impacts also provide some chest impact data. [34] A somewhat distributed force was used to simulate compression from a steering-wheel center-section by applying a 15 cm diameter load. Fractures were minimal up to 338 kg (745 lbs). Volunteers tolerated chest compressions involving 20% displacement with no injury and the cadavers showed rib fractures beginning above that 20% level ending in flail chest at 40% compression.[35]

A biomechanical ribcage model predicts that an adult male requires at least 572 ± 57 lbs of static chest mass to cause flail chest, a potentially lethal condition and a true compression fatality. Historical records exist of judicial "pressing" or the application of chest mass for interrogation or execution.[36] These records of judicial pressing show that about 600 lb is required to kill.

The concept of compression asphyxia as a cause of arrest-related or custodial deaths has been thoroughly debunked in the peer review literature.[7,10,11]

Figure 3. Volunteer in prone restrained position connected to spirometer.[25]

Prone and Positional Asphyxia

Similarly, people have died from positional asphyxia. Perhaps the most common form of this is people trapped upside down in a car for long period of time.[23,37] This concept also has been carried over and misapplied in an attempt to blame the prone position for arrest-related or custodial deaths.[4]

In fact, there have been 2 very large studies covering 1000s of forceful arrests that have shown no increased risk with prone restraint.[38,39] In fact, researchers are now arguing that the prone position is *preferred* as it leads to increased control and decreased subject and officer injury risks. See

Figure 3 in which a volunteer is restrained in a prone position while breathing thru spirometry instrumentation. There is no clinically significant reduction in breathing capability.[25]

Parkes studied breathing by seated individuals forced to lean forward. [40] See Figure 4. The only clinically significant respiratory reduction seen with this restraint was with obese subjects as their abdominal mass interfered with diaphragmatic breathing.

Figure 4. A seated position with subject forced to lean forward can interfere with breathing — but only with an obese individual (not shown here).[40]

Restraint Asphyxia

Restraint asphyxia is another speculative theory to explain arrest-related or custodial deaths. This has also been thoroughly debunked.[38,39,41-43] Impressive experiments have been done in which volunteers were: (1) prone, (2) hog-tied, and (3) compressed with up to 225 pounds on the back.[25] See Figure 5.

The scientific literature on restraint has been nicely summarized by Barnett.[44] He reported:

> The reduction in spirometry measures was proportional to the extent of the restriction imposed by position, increasing weight applied on the torso and increasing obesity in the seated flexed position. The literature did not report that the reductions seen were clinically significant except for Parkes et al. who reported the reductions seen in the flexed seated position with obese individuals were operationally significant.

In other words, the only clinically significant respiratory reduction seen in restraint is with obese individuals forced into a seated position (and forced to

lean forward) as their abdominal mass can interfere with diaphragmatic breathing.[40]

Figure 5. Maximally restrained prone subjects with 225 lb on the back have sufficient ventilation.[45]

Junk Science Under Different Names:

There are 3 intuitively appealing and often accepted theories for arrest-related and custodial deaths that are simply not supported by the peer-reviewed scientific literature. These are: compression asphyxia, restraint asphyxia, and positional (prone) asphyxia. They are basically 3 flavors of the same fundamental theory and they are all unsupported.[38,39,41-43,46]

Some continue to preach the anachronistic myth that prone positioning interferes with breathing. No matter how many studies have refuted this, it continues to be brought up. Of course, experts that raise this issue, do so without citations to the scientific literature since the literature does not support this old hypothesis.

In 2015, my colleagues and I authored the following summary of the situation in a lengthy review letter:[47]

In 2007, Michaelwitz investigated the ventilatory and metabolic demands in healthy adults who had been placed in the prone maximal restraint position (PMRP).[25] Maximal voluntary ventilation (MVV) was measured in seated subjects (n=30), in the PMRP (hogtied), and when prone with up to 90.1 or 102.3 kg of weight on their backs. MVV with >100 kg on their backs was 70% of the seated MVV (122±28 and 156±38 L/min, respectively; p<.001). However measurable decreases were observed in a second phase of the study when subjects were made to struggle vigorously before being studied; a decline in maximal minute ventilation (MMV) of 44% was observed. The researchers concluded the decrease in

MVV was of no clinical importance in these subjects, and that even in PMRP ventilatory exchanges was still adequate to supply the ventilatory needs, a judgement that would be shared by any pulmonologist.

In 2012, Hall published her epidemiological study "Incidence and outcome of prone positioning following police use of force."[48] In her study, data from a single police force serving >1.1 million people were collected for 3 consecutive years. Officers prospectively documented the final position of the subject, among other data points, via electronic study forms embedded in standard force reporting forms. Final resting position was available for 1255/ 1269 subjects. Force was required in 1269 cases. The majority (52%) were not even left in a prone position. There was 1 death, and that occurred in a prisoner not in the prone position. The authors concluded "prone positioning was common and was not associated with death in our cohort of consecutive subjects following police use of force." In 2015, Hall published her further study reporting 4828 consecutive force events in seven police agencies in four cities, concluding that their data support the human laboratory data that the prone position has no clinically significant effects on subject physiology.[38]

In 2013, Savaser's group evaluated the effect of maximal prone restraint (PMPR) on a group aged 22–42 years old.[43] Each volunteer was hogtied and tested in five different positions: supine, prone, prone maximal restraint with no weight force, prone maximal restraint with 50 lbs added to the subject's back, and prone maximal restraint with 100 lbs added to the subject's back for three minutes. Heart rate (HR), blood pressure (BP) and oxygenation saturation (O2 sat) were monitored for each volunteer in each position. In addition, echocardiography was performed to measure left ventricular outflow tract diameter. HR, MAP or O2 sat were statistically no different in any of the positions.

In 2014, Sloane extended the work even further measuring the ventilatory and cardiovascular parameters in 10 intensely exercising volunteers (85% of their measured VO2 max) who were placed in PMPR after exercising and then studied while in three different positions for 15 minutes: (1) seated with hands behind the back, (2) prone with arms to the sides, and (3) PMPR position.[49] Cardiovascular parameters (oxygenation, stroke volume, inferior vena cava diameter, cardiac output, cardiac index, oxygenation, stroke volume, IVC diameter, cardiac output and cardiac index) were all measured. There was no evidence of hypoxia or hypoventilation during any of the monitored 15-minute position periods. Numerous other papers confirm the findings summated above.

In 2016, Karch published a review article on arrest-related-death which included the following relevant points, here paraphrased:[50]

1. "Positional asphyxia" or "restraint asphyxia," the theories most frequently proposed, are terms often used synonymously. The term "restraint asphyxia" came into use when the notion of "positional asphyxia" fell from favor (it was retracted in court testimony by its author, Reay) and was replaced with the phrase "restraint asphyxia," which is used in exactly the same way, and should be considered to have the same meaning.
2. Those who accept the theory of "positional or restraint asphyxia" assume that prone positioning is clearly harmful, even though all of the available peer-reviewed evidence suggests that quite the opposite is the case.
3. Attempts at introducing the newly defined "positional asphyxia" into the court system have been rejected by several United States courts. In Garcia v City and County of San Francisco (State of California, Superior Court, Case #984e221), the presiding judge ruled that "reliance by plaintiffs on the theory of positional asphyxia is irrelevant … the original proponent of the theory, Dr. Donald Reay, has now retracted

it … Indeed, even Dr. Reay himself acknowledges the 1997 UCSD (University of California, San Diego) study refutes his earlier work. Everyone now agrees that there is no scientific evidence to support the idea that hog-tying or any other body position plays any role in causing life-threatening respiratory effects."

4. Positional asphyxia, as the term is used in court today, is an interesting hypothesis unsupported by any experimental data.

MRI studies of healthy volunteers show *lung perfusion is significantly greater in the prone position* than when studied in volunteers lying supine.[51] Ross and Hazlett conducted a prospective study examining 1085 violent arrests occurring over a 1-year period in 17 different police jurisdictions across the United States.[52] Police placed all of the arrestees in the prone position for 1-5 minutes; forcible measures were used to get them prone in 71% of cases. Handcuffs were used in 96% of the incidents and were first applied when the arrestee was prone in a ¼ of the cases. Hobble restraints were used in about ¼ of the cases. No deaths were recorded during the study and only 1 fracture occurred. The authors concluded "the use of prone position with violent arrestees is a safe restraint method."

Author has been an expert witness in law-enforcement litigation. mark@kroll.name

References:

1. Mumola C. Arrest-Related Deaths in the United States, 2003-2005. *Bureau of Justice Statistics Special Report* 2007(NCJ 219534):http://www.bjs.gov/index.cfm?ty=pbdetail&iid=379.
2. O'Halloran RL. Reenactment of circumstances in deaths related to restraint. *The American journal of forensic medicine and pathology.* 2004;25(3):190-193.
3. Miyaishi S, Yoshitome K, Yamamoto Y, Naka T, Ishizu H. Negligent homicide by traumatic asphyxia. *Int J Legal Med.* 2004;118(2):106-110.
4. Glatter K, Karch SB. Positional asphyxia: inadequate oxygen, or inadequate theory? *Forensic Sci Int.* 2004;141(2-3):201-202.
5. Vilke GM, Chan TC, Neuman T. Patient restraint in EMS. *Prehosp Emerg Care.* 2003;7(3):417-418; author reply 418-419.
6. O'Halloran RL, Frank JG. Asphyxial death during prone restraint revisited: a report of 21 cases. *The American journal of forensic medicine and pathology.* 2000;21(1):39-52.
7. Chan TC, Vilke GM, Neuman T. Restraint position and positional asphyxia. *The American journal of forensic medicine and pathology.* 2000;21(1):93.
8. Reay DT, Howard JD. Restraint position and positional asphyxia. *The American journal of forensic medicine and pathology.* 1999;20(3):300-301.
9. Howard JD, Reay DT. Positional asphyxia. *Ann Emerg Med.* 1998;32(1):116-118.
10. Chan TC, Vilke GM, Neuman T. Reexamination of custody restraint position and positional asphyxia. *The American journal of forensic medicine and pathology.* 1998;19(3):201-205.
11. Chan TC, Vilke GM, Neuman T, Clausen JL. Restraint position and positional asphyxia. *Ann Emerg Med.* 1997;30(5):578-586.
12. Karch SB, Wetli CV. Agitated delirium versus positional asphyxia. *Ann Emerg Med.* 1995;26(6):760-761.
13. Shamblin JR, McGoon DC. Acute Thoracic Compression with Traumatic Asphyxia; Report of Six Cases. *Arch Surg.* 1963;87:967-975.
14. Furuya Y. Experimental traumatic asphyxia (1)--grades of thoracic compression and mortality. *Igaku Kenkyu.* 1981;51(2):117-119.
15. Gill JR, Landi K. Traumatic asphyxial deaths due to an uncontrolled crowd. *The American journal of forensic medicine and pathology.* 2004;25(4):358-361.
16. Byard RW, Wick R, Simpson E, Gilbert JD. The pathological features and circumstances of death of lethal crush/traumatic asphyxia in adults--a 25-year study. *Forensic Sci Int.* 2006;159(2-3):200-205.
17. Cosio MQ. Soda pop vending machine injuries. *JAMA.* 1988;260(18):2697-2699.

18. Champa JR, Hennrikus WL, Gerardi JA, LaPoint JM. Four cases of injury involving soda vending machines. *J Orthop Trauma.* 1989;3(1):64-67.
19. Spitz DJ, Spitz WU. Killer pop machines. *Journal of forensic sciences.* 1990;35(2):490-492.
20. Cosio MQ, Taylor GW. Soda pop vending machine injuries: an update. *J Orthop Trauma.* 1992;6(2):186-189.
21. Lee MC, Wong SS, Chu JJ, et al. Traumatic asphyxia. *Ann Thorac Surg.* 1991;51(1):86-88.
22. Pomara C, Turillazzi E, Neri M, et al. A multidisciplinary approach to the investigation of a collapsed building. *The American journal of forensic medicine and pathology.* 2010;31(3):264-268.
23. Byard RW, Wick R, Gilbert JD. Conditions and circumstances predisposing to death from positional asphyxia in adults. *Journal of forensic and legal medicine.* 2008;15(7):415-419.
24. Fernando T, Byard RW. Positional asphyxia without active restraint following an assault. *Journal of forensic sciences.* 2013;58(6):1633-1635.
25. Michalewicz BA, Chan TC, Vilke GM, Levy SS, Neuman TS, Kolkhorst FW. Ventilatory and metabolic demands during aggressive physical restraint in healthy adults. *Journal of forensic sciences.* 2007;52(1):171-175.
26. Sklar DP, Baack B, McFeeley P, Osler T, Marder E, Demarest G. Traumatic asphyxia in New Mexico: a five-year experience. *Am J Emerg Med.* 1988;6(3):219-223.
27. Vega RS, Adams VI. Suffocation in motor vehicle crashes. *The American journal of forensic medicine and pathology.* 2004;25(2):101-107.
28. Velmahos GC, Vassiliu P, Chan LS, Murray JA, Berne TV, Demetriades D. Influence of flail chest on outcome among patients with severe thoracic cage trauma. *Int Surg.* 2002;87(4):240-244.
29. Davignon K, Kwo J, Bigatello LM. Pathophysiology and management of the flail chest. *Minerva Anestesiol.* 2004;70(4):193-199.
30. Shearer MO, Banks JM, Silva G, Sackner MA. Lung ventilation during diaphragmatic breathing. *Phys Ther.* 1972;52(2):139-148.
31. Lee JS, Lee MS, Lee JY, Cornelissen G, Otsuka K, Halberg F. Effects of diaphragmatic breathing on ambulatory blood pressure and heart rate. *Biomed Pharmacother.* 2003;57 Suppl 1:87s-91s.
32. Wardrope J, Ryan F, Clark G, Venables G, Crosby AC, Redgrave P. The Hillsborough tragedy. *BMJ.* 1991;303(6814):1381-1385.
33. Mall NA, Buchowski J, Zebala L, Brophy RH, Wright RW, Matava MJ. Spine and axial skeleton injuries in the National Football League. *Am J Sports Med.* 2012;40(8):1755-1761.
34. Kroell CK, Schneider DC, Nahum AM. Impact tolerance and response of the human thorax II. Paper presented at: Stapp Car Crash Conference Proceedings1974.
35. Kroell C. Thoracic response to blunt frontal loading. In: Engineers SoA, ed. *The Humun Thorax-Anatomy, Injury, and Biomechanics.* Vol P-67. Warrendale, PA.: Society of Automotive Engineers; 1976.
36. Mckenzie A. "This Death Some Strong and Stout Hearted Man Doth Choose": The Practice of Peine Forte et Dure in Seventeenth- and Eighteenth-Century England. *Law and History Review.* 2005;23(2):279-312.
37. Conroy C, Stanley C, Eastman AB, et al. Asphyxia: a rare cause of death for motor vehicle crash occupants. *The American journal of forensic medicine and pathology.* 2008;29(1):14-18.
38. Hall C. Restraint in police use of force events: examining sudden in custody death for prone and not-prone positions. *J Forensic and Legal Medicine.* 2015;JCFM-E-2404R1(Epublished).
39. Ross D. A Prospective Analysis of the Violent Prone Restraint Incident Outcomes in Policing. *Technical Consultant Research Report.* 2014.
40. Parkes J, Thake D, Price M. Effect of seated restraint and body size on lung function. *Med Sci Law.* 2011;51(3):177-181.
41. Vilke GM, Chan TC, Savaser D, Neuman T. Response to "Hemodynamic consequences of restraints in the prone position in excited delirium syndrome". *Journal of forensic and legal medicine.* 2014;27:82-84.
42. Michaud A. Hemodynamic consequences of restraints in the prone position in excited delirium syndrome. *Journal of forensic and legal medicine.* 2014;27:85-86.
43. Savaser DJ, Campbell C, Castillo EM, et al. The effect of the prone maximal restraint position with and without weight force on cardiac output and other hemodynamic measures. *Journal of forensic and legal medicine.* 2013;20(8):991-995.
44. Barnett R, Stirling C, Pandyan AD. A review of the scientific literature related to the adverse impact of physical restraint: gaining a clearer understanding of the physiological factors involved in cases of restraint-related death. *Med Sci Law.* 2012;52:137-142.
45. Chan TC, Neuman T, Clausen J, Eisele J, Vilke GM. Weight force during prone restraint and respiratory function. *The American journal of forensic medicine and pathology.* 2004;25(3):185-189.

46. Vilke GM, Sloane C, Castillo EM, Kolkhorst FW, Neuman TS, Chan TC. Evaluation of the ventilatory effects of a restraint chair on human subjects. *The Journal of emergency medicine.* 2011;40(6):714-718.
47. Karch SB, Brave MA, Kroll MW. On positional asphyxia and death in custody. *Med Sci Law.* 2015.
48. Hall CA, McHale AM, Kader AS, Stewart LC, MacCarthy CS, Fick GH. Incidence and outcome of prone positioning following police use of force in a prospective, consecutive cohort of subjects. *Journal of forensic and legal medicine.* 2012;19(2):83-89.
49. Sloane C, Chan TC, Kolkhorst F, Neuman T, Castillo EM, Vilke GM. Evaluation of the ventilatory effects of the prone maximum restraint (PMR) position on obese human subjects. *Forensic Sci Int.* 2014;237:86-89.
50. Karch SB. The problem of police-related cardiac arrest. *Journal of forensic and legal medicine.* 2016;41:36-41.
51. Prisk GK, Yamada K, Henderson AC, et al. Pulmonary perfusion in the prone and supine postures in the normal human lung. *J Appl Physiol (1985).* 2007;103(3):883-894.
52. Ross D, Hazlett M. Prospective Analysis of the Outcomes of Violent Prone Restraint Incidents in Policing. *Forensic Research & Criminology International Journal.* 2016;2(1):1-10.