# Influence of positive end-expiratory pressure on arterial blood pressure in mechanically ventilated trauma patients in the field: a retrospective cohort study

**Holger Herff[1,*], Dietmar Krappinger[2], Peter Paal[3], Wolfgang G. Voelckel[4], Volker Wenzel[5], Helmut Trimmel[6]**
1 Department of Anesthesiology and Perioperative Intensive Care Medicine, University of Cologne, Cologne, Germany
2 Department of Trauma Surgery and Sports Medicine, Innsbruck Medical University, Innsbruck, Austria
3 Department of Anesthesiology and Intensive Care Medicine, Hospitallers Brothers Hospital, Paracelsus Medical University, Salzburg, Austria
4 Institute for Anesthesiology and Critical Care Medicine, Trauma Hospital Salzburg, Salzburg, Austria
5 Department of Anesthesiology, Intensive Care Medicine, Emergency Medicine and Pain Therapy, Klinikum Friedrichshafen, Friedrichshafen, Germany
6 Department of Anesthesiology, Emergency and Critical Care Medicine, County Hospital Wiener Neustadt, Wiener Neustadt, Austria

*Correspondence to: Holger Herff, MD, holger.herff@uk-koeln.de.
orcid: 0000-0002-7380-4013 (Holger Herff)

## Abstract

Ventilation with positive end-expiratory pressure (PEEP) may result in decreased venous return to the heart and therefore decrease cardiac output. We evaluated the influence of PEEP ventilation on arterial blood pressure in the field in 296 posttraumatic intubated patients being treated by a helicopter emergency medical service in a retrospective cohort study. Initial systolic blood pressure on the scene, upon hospital admission and their mean difference were compared between patients being ventilated with no/low PEEP (0–0.3 kPa) and moderate PEEP (0.3–1 kPa). In a subgroup analysis of initially hemodynamic unstable patients (systolic blood pressure < 80 mmHg), systolic blood pressure was compared between patients being ventilated with no/low or moderate PEEP. Further, the mean difference between initial systolic blood pressure and upon hospital admission was correlated with the chosen PEEP. Systolic arterial blood pressure of patients being ventilated with no/low PEEP improved from 105 ± 36 mmHg to 112 ± 38 mmHg, and that of patients being ventilated with moderate PEEP improved from 105 ± 38 mmHg to 119 ± 27 mmHg. In initially unstable patients being ventilated with no/low PEEP systolic blood pressure improved from initially 55 ± 36 mmHg to 78 ± 30 mmHg upon hospital admission, and in those being ventilated with moderate PEEP, the systolic blood pressure improved from 43 ± 38 mmHg to 91 ± 27 mmHg. There was no significant correlation between the chosen PEEP and the mean difference of systolic blood pressure (Pearson's correlation, $r = 0.07$, $P = 0.17$). Ventilation with moderate PEEP has no adverse effect on arterial systolic blood pressure in this cohort of trauma patients requiring mechanical ventilation. Initially unstable patients being ventilated with moderate PEEP tend to be hemodynamically more stable.

**Key words:** arterial blood pressure; death; hemorrhage; Helicopter Emergency Medical Service; mechanical ventilation; PEEP; shock; trauma

**doi:** 10.4103/2045-9912.344979
**How to cite this article:** Herff H, Krappinger D, Paal P, Voelckel WG, Wenzel V, Trimmel H. Influence of positive end-expiratory pressure on arterial blood pressure in mechanically ventilated trauma patients in the field: a retrospective cohort study. Med Gas Res. 2023;13(2):49-52.
**Funding:** This study was supported, in part, by the Science Foundation of the Austrian National Bank (No. 11448), the Helicopter Emergency Medical Service of the Austrian Automobile and Touring Club (OeAMTC) and institutional resources.

## Introduction

In a traffic accident, an 18-year-old motorcyclist was severely injured suffering severe chest trauma and had to be intubated in the field. After intubation, blood pressure decreased rapidly and cardiovascular collapse was imminent while the patient was initially ventilated with 10 $cmH_2O$ positive end-expiratory pressure (PEEP). After reducing PEEP to 0 $cmH_2O$, the hemodynamic function stabilized transiently en route to the next trauma center. After hospital admission, the patient died in the emergency room due to a rupture of the right subclavian artery with uncontrolled intrathoracic bleeding (unpublished data), which is in accordance with multiple recommendations.[1-4]

Although this patient could not be saved, this example demonstrates the potential of decreased PEEP to stabilize hemodynamic function in acute hemorrhagic shock. PEEP increases intrathoracic pressure, reduces return of venous blood to the heart, and in consequence reduces cardiac output.[5] In an animal experiment, the lifesaving potential of omitting PEEP or even hypoventilation was demonstrated.[6,7] Even if PEEP will be unlike to most probably not directly result in death, its ability to reduce arterial blood pressure may endanger patients in severe hemorrhagic shock. For example, even hypotonic episodes of only a few minutes could significantly decrease survival chances of trauma patients with critically decreased blood pressure, especially of those with concurrent brain injuries.[8]

Therefore, more invasive ventilation should impair hemodynamic stability as can be seen every day in intensive care medicine. The purpose of this retrospective study was to generate a hypothesis for further research by finding any influence of PEEP on hemodynamic stability. Therefore, we evaluated retrospectively the influence of PEEP on arterial systolic blood pressure in mechanically ventilated trauma patients in the scene call data bank of a Helicopter Emergency

Medical Service (HEMS). Our formal hypothesis was that upon hospital admission there would be no differences in arterial blood pressure between trauma patients ventilated with no/low PEEP 0–0.3 kPa (0–5 $cmH_2O$) and patients being ventilated with moderate PEEP 0.4–1 kPa (5–10 $cmH_2O$).

## Subjects and Methods

### Subjects

From 2275 trauma patients, 296 cases of mechanically ventilated trauma patients (> 18 years) of the HEMS of the Austrian Automobile and Touring Club between 2003–2007 were retrospectively analyzed according to the *Declaration of Helsinki* in a retrospective cohort study.

### Intervention

The ventilated patients were divided in two groups with 0–0.3 kPa (0–3 $cmH_2O$; no/low PEEP group) and with 0.4–1 kPa (4–10 $cmH_2O$; moderate PEEP group) (**Figure 1**). Initial arterial systolic and the arterial systolic blood pressure upon hospital admission, were generally determined with classical Riva Rocci method by the HEMS personnel.[9] Since the measured arterial systolic blood pressures and the PEEP level must be documented in the electronic system of the HEMS, this data could be retrospectively analyzed. We compared initial arterial systolic blood pressure upon arrival of the HEMS on the scene, with the same value upon hospital admission in both the no/low and moderate PEEP groups. Additionally, a subgroup analysis of PEEP-influence in initially unstable patients (arterial systolic blood pressure < 80 mmHg) was performed.

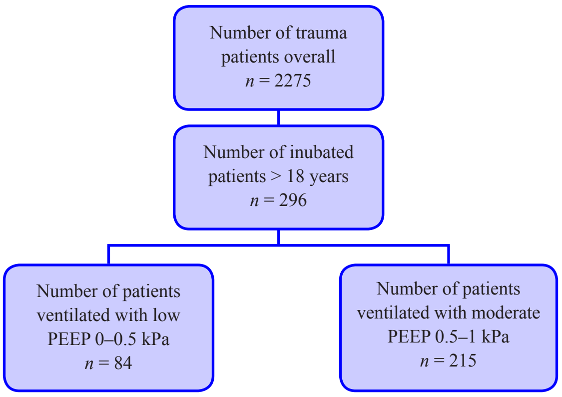


**Figure 1: Flow chart of the study.**
Note: PEEP: Positive end-expiratory pressure.

### Statistical analysis

SPSS 12.0 (SPSS, Chicago, IL, USA) was used for the statistical analysis. Data are shown as mean ± standard deviation (SD). A Student's *t*-test for independent samples or a Mann-Whitney test was used for the statistical analysis. Correlations were quantified using Pearson's correlation coefficient. The Kolmogorov-Smirnov test was used to determine the distribution type. The probability level was set at 0.05.

## Results

Mean PEEP in the no/low PEEP ($n$ = 84) group was 1 ± 0 $cmH_2O$ and 5 ± 1 $cmH_2O$ in the moderate PEEP group ($n$ = 215), respectively. There was no difference between the no/low and moderate PEEP groups in regard of mean initial systolic arterial blood pressure upon arrival of the HEMS ($P$ = 0.54; **Table 1**). At hospital admission those treated with moderate PEEP showed an even better arterial systolic blood pressure, but the difference was not significant ($P$ = 0.147; **Table 1**). In the subgroup of initially hemodynamic unstable patients the arterial systolic blood pressure was comparable between groups at arrival of the HEMS on the scene; but it was significantly higher upon hospital admission in the moderate PEEP group compared with the no/low PEEP group ($P$ = 0.04; **Table 2**). There was no significant correlation between the PEEP level and the difference between initial arterial systolic blood pressure and that upon hospital admission ($r$ = 0.07, $P$ = 0.17; **Figure 2**).

**Table 1: Systolic arterial blood pressure (mmHg) in all mechanically ventilated trauma patients**

| | No/low PEEP (0–3 $cmH_2O$) ($n$ = 84) | Moderate PEEP (4–10 $cmH_2O$) ($n$ = 215) |
|---|---|---|
| Initial | 105±36 | 105±38 |
| Hospital | 112±30 | 117±27 |
| Difference | 7±28 | 12±31 |

Note: Data are expressed as mean ± SD. PEEP: Positive end-expiratory pressure.

**Table 2: Systolic arterial blood pressure (mmHg) in the subgroup of initially hemodynamically unstable mechanically ventilated trauma patients (arterial systolic blood pressure < 80 mmHg)**

| | No/low PEEP ($n$ = 23) | Moderate PEEP ($n$ = 45) |
|---|---|---|
| Initial | 55±36 | 43±38 |
| Hospital | 78±30 | 91±27 |
| Difference | 23±38* | 48±36* |

Note: Data are expressed as mean ± SD. *$P$ < 0.05, *vs.* no/low PEEP group. PEEP: Positive end-expiratory pressure.

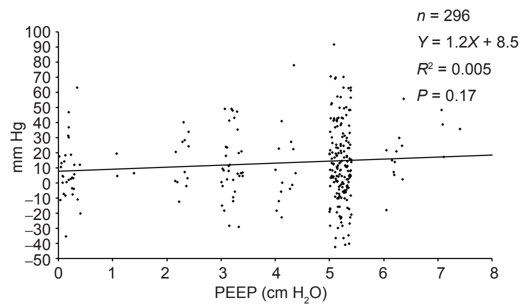


**Figure 2: PEEP level and the difference between initial arterial systolic blood pressure and that upon hospital admission in mechanically ventilated trauma patients using Pearson's analysis.**
Note: There is no significant correlation between these two parameters and distribution seems to be randomly assigned ($r$ = 0.07, $P$ = 0.17).

## Discussion

This retrospective analysis failed showed no adverse effects from moderate PEEP on hemodynamic function in 296 mechanically ventilated trauma patients in the field. Moreover, initially hemodynamical unstable patients being ventilated with moderate PEEP tended to be hemodynamically more stable. Correlation analysis revealed no/low PEEP-influence on systolic arterial blood pressure.

While a moderate PEEP of 5 $cmH_2O$ is widely used during routine anesthesia in order to compensate for reduced functional residual capacity, and to improve oxygenation, PEEP-mediated intrathoracic pressure has a significant negative impact on venous return and in consequence on blood pressure and possibly survival in severe hemorrhagic shock.[6,10] Thus, in previous animal and patient studies increasing PEEP-levels had adverse effects on cardiovascular function when tidal volume or respiratory rate were kept constant.[5,6,11] Therefore, emergency care concepts postulated no or low PEEP in order to achieve a better arterial blood pressure.[12] This concept can be even further improved by applying negative end-expiratory pressure,[6,11] which may further increase venous return to the heart and subsequently cardiac output and vital organ perfusion.[11,12]

While this phenomenon of antiproportional development of blood pressure and airway pressure even in healthy volunteers is common knowledge, or could be seen in intensive care units,[13] we did not see this phenomenon in our retrospective analysis. Even the initially unstable trauma patients did not benefit from no/low PEEP only, although the underlying pathophysiology provided an excellent setting for no/low PEEP. One important reason might be confounding interventions such as fluid resuscitation and vasopressor infusion provided by the HEMS team.[14,15] In previous animal studies vasopressor and fluid resuscitation had been deliberately withheld to visualize the effects of PEEP on blood pressure.[6,11] Further, in these laboratory studies the differences in PEEP levels were far larger than in our analysis[6,11]; for example, in one study of Krismer et al.6 0 $cmH_2O$ were compared with 10 $cmH_2O$. Thus, the small mean pressure difference of 4 $cmH_2O$ between the no/low PEEP (1 ± 0 $cmH_2O$) and the moderate PEEP (5 ± 1 $cmH_2O$) group in our analysis may be an additional reason for a missing influence on hemodynamic function. Further, we know that even during cardiopulmonary resuscitation, NO or moderate PEEP levels can be tolerated quite well.[16]

Despite pathophysiological considerations the effect of decreased PEEP levels on blood pressure was not visible in this medium sized retrospective cohort ($n$ = 296). Obviously, it may be really difficult to isolate any effect of ventilation modes on hemodynamic stability in a field study. In this regard, a prospective study on this hypothesis has to strictly prospectively control confounding elements and most probably must be large. Further, the PEEP difference between groups most probably needs to be larger than 4 $cmH_2O$ to be able to show any effects on arterial blood pressure. While no artificially high PEEP levels could be used due to ethical reasons in the "control group," it might be more promising to evaluate a concept of negative intrapulmonary pressure instead of "only" a zero PEEP concept. Examples for this strategy might be the use of negative inspiratory threshold devices in spontaneously breathing trauma patients,[12] or negative end-expiratory airway pressure in mechanically ventilated patients.[11] Further, confounding interventions such as volume- or vasopressor-resuscitation or temperature regulation have to be excluded as far as possible,[4,11,17,18] which will be extremely difficult if not impossible due to ethical reasons in a prospective human study. Thus, while certain interventions may be sound in the laboratory setting, real-life clinical settings may be complex to prove them in the field. There are multiple methods for oxygenation and ventilation[19-27] and multiple reasons to apply (moderate) PEEP levels in multiple trauma patients: one of the most important is the prevention of atelectasis resulting in less shunting volume and finally better oxygenation. Further, many multiple trauma patients suffer from severe thoracical trauma where PEEP may be lifesaving by alveolar stabilization. Thus, concepts of improving hemodynamic stability by applying less PEEP always have to take in account and weigh on adverse effects on oxygenation parameters by less PEEP. Last, tracheal intubation always imposes the risk of technical or medical failure.[28-32]

One important limitation of this retrospective analysis is that we are not able to provide information on the fluid or vasopressor therapy applied to each individual patient. Thus, it is hard to draw a solid conclusion that moderate PEEP ventilation had no adverse effect on arterial systolic blood pressure. Further, we are not able to provide information on the exact severity of the patient's injuries except of "they obviously needed mechanical ventilation." However, usually no patient is intubated by experienced HEMS physicians without substantial injuries, leaving a cohort of generally either multiple trauma or severely brain-injured patients. Further, we cannot conclude from arterial systolic blood pressure on cardiac output; systolic arterial blood pressure was only a surrogate parameter of hemodynamic stability. Additionally, a retrospective analysis is a limitation by itself, not allowing drawing any conclusions on the cause of an observed phenomenon. Further, while we might be able to explain no superiority of the no/low PEEP patients, we are not able to explain better arterial systolic blood pressure upon hospital admission in the subgroup of initially hemodynamical unstable patients treated with moderate PEEP. We might speculate that probably HEMS physicians treating pulmonary function more aggressively with moderate PEEP levels may also be more aggressive in treating hypotension and may therefore achieve higher systolic arterial blood pressure upon hospital admission. But we cannot prove this based on our data.

The no/low and moderate PEEP groups with 0–5 and 5–10 $cmH_2O$, respectively, were voluntarily chosen; this was based on clinical and experimental experience of the ability of PEEP to influence hemodynamic stability.[2] However, correlation, that is not based on comparison between different groups, revealed arterial systolic pressure being completely independent from PEEP in this cohort of 296 patients. Further, both groups were different in size which may have the potential to reduce reliability of statistical methods. Last, the data were assembled over 10 years ago; however treatment in multiple traumas did not really change. Thus, this data provides still useful information for the future.

In conclusion, ventilation with moderate PEEP had no adverse effect on arterial systolic blood pressure in this cohort of trauma patients requiring mechanical ventilation. Initially unstable patients being ventilated with moderate PEEP tended to be hemodynamically more stable.

## Author contributions

Study concept: HH, WGV and VW; data acquisition, ethics committee approval: HT; data analysis: HH, DK; statistics: DK; data interpretation: PP; original draft: HH, PP and VW; funding: WGV and VW. All authors approved the final version of the manuscript.

## Conflicts of interest

There are no competing interests in regard of this study.

## Open access statement



## References


1. Soar J, Becker LB, Berg KM, et al. Cardiopulmonary resuscitation in special circumstances. *Lancet.* 2021;398:1257-1268.
2. Roy S, Soteras I, Sheets A, et al. Guidelines for mountain rescue during the COVID-19 pandemic: official guidelines of the International Commission for Alpine Rescue. *High Alt Med Biol.* 2021;22:128-141.
3. Mittermair C, Foidl E, Wallner B, Brugger H, Paal P. Extreme cooling rates in avalanche victims: case report and narrative review. *High Alt Med Biol*. 2021;22:235-240.
4. Harve-Rytsälä H, Paal P, Kurola J. To the Moon and beyond-Pushing boundaries in critical emergency medicine. *Acta Anaesthesiol Scand.* 2021;65:717-718.
5. Hodgkin BC, Lambrew CT, Lawrence FH, 3rd, Angelakos ET. Effects of PEEP and of increased frequency of ventilation during CPR. *Crit Care Med.* 1980;8:123-126.
6. Krismer AC, Wenzel V, Lindner KH, et al. Influence of positive end-expiratory pressure ventilation on survival during severe hemorrhagic shock. *Ann Emerg Med.* 2005;46:337-342.
7. Taghavi S, Jayarajan SN, Ferrer LM, et al. "Permissive hypoventilation" in a swine model of hemorrhagic shock. *J Trauma Acute Care Surg*. 2014;77:14-19.
8. Maeda Y, Ichikawa R, Misawa J, et al. External validation of the TRISS, CRASH, and IMPACT prognostic models in severe traumatic brain injury in Japan. *PLoS One*. 2019;14:e0221791.
9. Li Y, Li F, Li Y, et al. Effect of cuff positioning on the accuracy of blood pressure measurement with automated electronic blood pressure monitors. *J Clin Hypertens (Greenwich)*. 2020;22:1163-1172.
10. Vieillard-Baron A, Matthay M, Teboul JL, et al. Experts' opinion on management of hemodynamics in ARDS patients: focus on the effects of mechanical ventilation. *Intensive Care Med.* 2016;42:739-749.
11. Krismer AC, Wenzel V, Lindner KH, et al. Influence of negative expiratory pressure ventilation on hemodynamic variables during severe hemorrhagic shock. *Crit Care Med*. 2006;34:2175-2181.
12. Convertino VA, Ryan KL, Rickards CA, et al. Optimizing the respiratory pump: harnessing inspiratory resistance to treat systemic hypotension. *Respir Care.* 2011;56:846-857.
13. Algera AG, Pisani L, Chaves RCF, et al. Effects of peep on lung injury, pulmonary function, systemic circulation and mortality in animals with uninjured lungs-a systematic review. *Ann Transl Med*. 2018;6:25.
14. Du GB, Slater H, Goldfarb IW. Influences of different resuscitation regimens on acute early weight gain in extensively burned patients. *Burns.* 1991;17:147-150.
15. Krismer AC, Wenzel V, Voelckel WG, et al. Employing vasopressin as an adjunct vasopressor in uncontrolled traumatic hemorrhagic shock. Three cases and a brief analysis of the literature. *Anaesthesist.* 2005;54:220-224.
16. Ido Y, Goto H, Lavin MJ, Robinson JD, Mangold JV, Arakawa K. Effects of positive end-expiratory pressure on carotid blood flow during closed-chest cardiopulmonary resuscitation in dogs. *Anesth Analg.* 1982;61:557-560.
17. Herff H, Schroeder DC, Bowden K, Paal P, Mitterlechner T, Wenzel V. Temperature loss by ventilation in a calorimetric bench model. *Med Gas Res.* 2020;10:27-29.
18. Guschlbauer M, Maul AC, Yan X, et al. Zero-heat-flux thermometry for non-invasive measurement of core body temperature in pigs. *PLoS One*. 2016;11:e0150759.
19. Herff H, Wetsch WA, Finke S, et al. Oxygenation laryngoscope vs. nasal standard and nasal high flow oxygenation in a technical simulation of apnoeic oxygenation. *BMC Emerg Med*. 2021;21:12.
20. Wetsch WA, Herff H, Schroeder DC, Sander D, Böttiger BW, Finke SR. Efficiency of different flows for apneic oxygenation when using high flow nasal oxygen application - a technical simulation. *BMC Anesthesiol.* 2021;21:239.
21. Wetsch WA, Schroeder DC, Finke SR, et al. A special oropharyngeal oxygenation device to facilitate apneic oxygenation in comparison to high flow oxygenation devices. *Med Gas Res.* 2022;12:28-31.
22. Ecker H, Kolvenbach S, Stranz S, Herff H, Wetsch WA. Comparison of the novel VieScope with conventional and video laryngoscope in a difficult airway scenario - a randomized, controlled simulation trial. *BMC Emerg Med*. 2021;21:90.
23. Schroeder DC, Wetsch WA, Finke SR, Dusse F, Böttiger BW, Herff H. Apneic laryngeal oxygenation during elective fiberoptic intubation - a technical simulation. *BMC Anesthesiol.* 2020;20:300.
24. de Wolf MW, Gottschall R, Preussler NP, Paxian M, Enk D. Emergency ventilation with the Ventrain(®) through an airway exchange catheter in a porcine model of complete upper airway obstruction. *Can J Anaesth.* 2017;64:37-44.
25. Mendonca C, Mesbah A, Velayudhan A, Danha R. A randomised clinical trial comparing the flexible fibrescope and the Pentax Airway Scope (AWS)(®) for awake oral tracheal intubation. *Anaesthesia.* 2016;71:908-914.
26. Vourc'h M, Huard D, Feuillet F, et al. Preoxygenation in difficult airway management: high-flow oxygenation by nasal cannula versus face mask (the PREOPTIDAM study). Protocol for a single-centre randomised study. *BMJ Open*. 2019;9:e025909.
27. Saksitthichok B, Petnak T, So-Ngern A, Boonsarngsuk V. A prospective randomized comparative study of high-flow nasal cannula oxygen and non-invasive ventilation in hypoxemic patients undergoing diagnostic flexible bronchoscopy. *J Thorac Dis.* 2019;11:1929-1939.
28. Douglas N, Ng I, Nazeem F, et al. A randomised controlled trial comparing high-flow nasal oxygen with standard management for conscious sedation during bronchoscopy. *Anaesthesia.* 2018;73:169-176.
29. Frat JP, Ricard JD, Quenot JP, et al. Non-invasive ventilation versus high-flow nasal cannula oxygen therapy with apnoeic oxygenation for preoxygenation before intubation of patients with acute hypoxaemic respiratory failure: a randomised, multicentre, open-label trial. *Lancet Respir Med.* 2019;7:303-312.
30. Fong KM, Au SY, Ng GWY. Preoxygenation before intubation in adult patients with acute hypoxemic respiratory failure: a network meta-analysis of randomized trials. *Crit Care.* 2019;23:319.
31. Mitterlechner T, Paal P, Schroeder DC, Wenzel V, Herff H. Safer employment of nitrous oxide in anesthesia machines-a technical simulation. *Med Gas Res*. 2018;8:54-56.
32. Kumar P, Abhilasha, Sharma J, Kaur K, Bharadwaj M, Singh A. Evaluation of audible leak versus pressure volume loop closure for polyvinyl chloride cuff and polyurethane microcuff in endotracheal tube inflated with air: a prospective randomized study. *Med Gas Res*. 2021;11:6-11.


*Date of submission: September 25, 2020*
*Date of decision: January 5, 2021*
*Date of acceptance: February 18, 2021*
*Date of web publication: May 12, 2022*