

Efficacy of high-flow nasal prong therapy in trauma patients with rib fractures and high-risk features for respiratory deterioration: a randomized controlled trial

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ABSTRACT

Background Patients with rib fractures require analgesia, oxygen supplementation and physiotherapy. This combination has been shown to reduce morbidity and mortality due to rib fractures. There has been movement towards the use of high-flow nasal prong (HFNP) oxygen. However there are no studies demonstrating the effectiveness of HFNP in this population. The aim of this study was to compare HFNP to venturi mask (VM) in rib fracture patients.

Methods Randomized controlled trial. Patient population included patients with rib fractures and high-risk features (three or more rib fractures, flail segment, bilateral rib fractures, smoker or chronic obstructive pulmonary disease). Exclusion criteria included initial mechanical ventilation and contraindications to HFNP. Patients were randomized to HFNP or VM. Primary outcome was deterioration requiring mechanical invasive/non-invasive ventilation, or unplanned admission to intensive care unit. Secondary outcomes included mortality, length of stay, high dependency length of stay, comfort levels, breathing exertion levels (as measured by Borg Scale), oxygen saturation, respiratory rate, heart rate, chest X-ray and arterial blood gas parameters.

Results 220 patients (average age 60 years and average of four rib fractures each) were randomized to HFNP (n=113) and VM (n=107). There was no statistically significant difference in the primary outcome comparing HFNP and VM (6.2% vs. 6.5%, p=1.0). There were also no statistically significant differences in the secondary outcomes except for PaCO₂ (43.6 vs. 45.5, p=0.039)

Conclusion HFNP oxygen supplementation does not appear to be more effective than VM oxygen supplementation in patients with rib fractures.

INTRODUCTION

Rib fractures occur commonly as a result of blunt chest trauma and are associated with significant morbidity and mortality due to respiratory failure and pneumonia.¹⁻³ These complications affect up to 25% of patients with rib fractures, and resulting in escalation of care, admission to intensive care units (ICU) and increased length of hospital stays.^{4,5} Rib fractures are frequently associated with intrathoracic injuries including pulmonary contusions,

hemothorax, pneumothorax and aortic injury. Factors that increase the risk of complications from rib fractures include increasing age, number of rib fractures and pre-existing respiratory disease.^{3,6-8}

The two main goals of therapy are pain management and pulmonary care and support. There is strong evidence for providing good analgesia to facilitate volume expansion treatment and chest physiotherapy, aiming for deep breathing and effective cough to reduce secretions and prevent atelectasis.^{2,8-10} Oxygen supplementation is often included as supportive therapy added to bundles of care for patients with rib fractures.¹⁰⁻¹²

High-flow nasal prong (HFNP) oxygen (O₂) was first developed for neonates and has gained increasing use in adult patients for prevention and treatment of respiratory failure.¹³ High-flow humidified oxygen with flow rates from 30 to 100 L/min with high fraction of inspired oxygen (FiO₂) is able to be delivered.¹⁴ There have been proposed benefits of using HFNP O₂ including increased comfort, tolerance and increased mucociliary clearance.¹⁵⁻¹⁷ Positive end-expiratory pressure can be generated, preventing alveoli collapse. The washout of carbon dioxide (CO₂) and replacement with enriched O₂ purportedly decreases work of breathing and increases breathing effectiveness.^{13,14,17-19}

There is a significant cost associated with HFNP O₂, including the humidifier and the disposable delivery system as well as staff training and labor cost for the management of device.

Although there are studies examining the use of non-invasive ventilation (NIV) for blunt chest trauma,²⁰ there are no studies examining the optimal method of oxygen supplementation in preventing complications related to rib fractures.

The aim of this study was to compare high-flow oxygen therapy to venturi oxygen supplementation in preventing respiratory complications related to rib fractures and also assess patient's tolerance and comfort with the use of the devices.

METHODS

Study design

The study was a single-center, prospective randomized controlled trial aimed to assess the efficacy of HFNP therapy in trauma patients with risk factors for respiratory deterioration. Patients were allocated to receive HFNP therapy or oxygen via a

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venturi mask (VM) according to a computer-generated randomization program. Permuted block randomization was used.

Setting and participants

All trauma patients presenting to a level 1 trauma center in Sydney, New South Wales, Australia, were assessed for eligibility. The inclusion criteria were patients with rib fractures confirmed with CT imaging and one or more risk factors for respiratory deterioration: age greater than 55 years, three or more rib fractures, bilateral rib fractures, flail segment, smoker or known underlying respiratory disease. Exclusion criteria include: intubation prehospital or in emergency department, contraindication to HFNP (base of skull fracture, unstable facial fractures) and inability to consent (confusion, non-English speaking background).

Intervention

Patients were randomly allocated using a computer-generated sequence in a 1:1 ratio to either receive HFNP therapy or oxygen via a VM. VM was selected instead of nasal prongs so FiO_2 could be accurately delivered.²¹ All patients were admitted to a high dependency surgical or trauma unit. FiO_2 was initiated at 0.4. For patients allocated to HFNP, flow rate was initiated at 60L/min. All other treatment was as per standard hospital protocol including continuous monitoring in a high dependency unit (HDU), daily chest physiotherapy, analgesia including: paracetamol, non-steroidal anti-inflammatory drugs if not contraindicated, opioids via patient-controlled analgesia device and regional anesthesia as determined by the acute pain service. Patients underwent surgical stabilization of their rib fractures as determined by the attending trauma surgeon. FiO_2 for both HFNP and VM was titrated to maintain oxygen saturation (SpO_2) ≥ 95 . Patients with advanced chronic obstructive pulmonary disease were given supplementary O_2 for SaO_2 88% to 92%. For the HFNP cohort, the flow rate was maintained at 60L/min for at least 24 hours and then until SpO_2 was maintained on FiO_2 of 0.21.

Outcomes

The primary outcome was a composite endpoint of unplanned transfer to ICU due to respiratory deterioration, escalation of ventilation support, including NIV and intubation for mechanical ventilation. These patients were ICU medically reviewed and then accepted for admission to ICU due to their increasing respiratory distress and failure.

Secondary outcomes included mortality, hospital length of stay (LOS), HDU LOS and development of pneumonia. Daily measurements were recorded for arterial pH, partial pressure of oxygen in arterial blood (PaO_2), partial pressure of carbon dioxide in arterial blood (PaCO_2), peak flow and O_2 saturations. Comfort levels with the different modes of oxygen delivery were measured with the Likert scale.^{21 22} The perceived effort of breathing was measured with the modified Borg Scale.^{23 24} Results for the daily measurements were averaged during the first 3 days after hospital admission.

Statistical analysis

All statistical analyses were performed using Statistical Package for Social Sciences (SPSS) Predictive Analytics Software (PASW) V.24.0 (SPSS). Continuous data are presented as means and SD or medians and IQR (range from the 25th to the 75th percentile). χ^2 test or Fisher's exact test was used to compare proportions and to test for trends. The Student's t-test and Mann-Whitney U

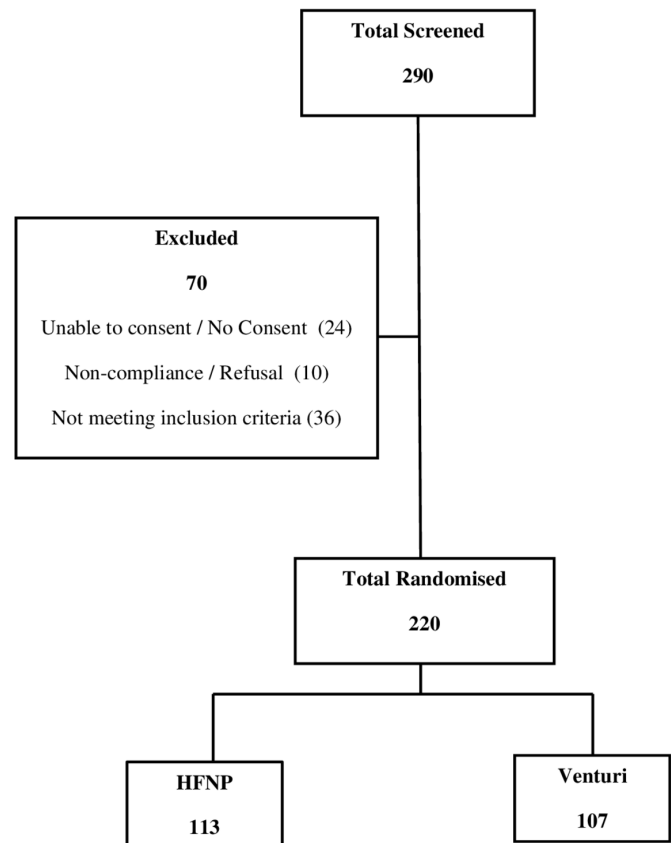


Figure 1 Randomization screening and exclusion flow diagram. HFNP, high-flow nasal prong.

test were used to compare unpaired groups of continuous data. Univariate analysis identified any significant differences. For all analyses, actual p values were reported and where possible, 95% CIs presented. All tests were two tailed. Differences were considered to be statistically significant at a $p < 0.05$ level.

The sample size was calculated to detect a 15% difference in the primary outcome with $\alpha = 0.05$ and power 80%.

RESULTS

During the study period 290 patients were screened for inclusion to the study (figure 1). Seventy patients were excluded in total. Thirty-six were excluded due to not meeting study inclusion criteria; 24 patients were unable to be consented; 10 patients refused or were not compliant with HFNP or VM after recruitment and were excluded from the study. On post hoc analysis, none of these exclusions achieved the primary outcome, that is, unplanned admission to ICU/escalation of O_2 therapy to invasive ventilation or NIV. Secondary outcome measures were unobtainable due to the patient refusing the required investigations. Therefore, the total number of study participants was 113 in HFNP group and 107 in VM group.

Table 1 demonstrates the demographics and clinical characteristics of included patients.

Table 2 shows there was no difference in the rates of unplanned transfer to ICU and/or escalation of ventilatory support between the HFNP group (6.2%) and VM group (6.5%), $p = 1.0$.

There was no difference in mortality, high dependency LOS or total hospital LOS, between the two groups. There was no difference in the Likert comfort scale or the modified Borg Scale of perceived breathlessness between the two groups. Respiratory

Table 1

	High-flow nasal prong O ₂ (n=113)	Venturi mask O ₂ (n=108)
Age	60.9 (SD=18.3)	59.8 (SD=18.7)
Sex (M:F)	89:24	81:27
Injury Severity Score	12.2 (SD=5.9)	12.0 (6.6)
Chest Abbreviated Injury Score	3 (2.5)	3 (2.5)
Rib fractures, n	4 (3.6)	4 (3.5)
Flail segment present (%)	19 (16.8)	16 (14.8)
Bilateral rib fractures (%)	15 (13.3)	15 (13.9)
Smoker or COPD (%)	38 (33.6)	37 (34.3)
Rib fixation (%)	4 (3.5)	5 (4.7)

rates and oxygen saturations were no different between the two groups.

Arterial blood gas results showed no difference in pH or PaO₂. PaCO₂ for HFNP group was lower (43.6 mm Hg, SD=5.6) compared with the VM group (45.5 mm Hg, SD=6.5). This was a statistically significant difference (p=0.032). Peak flow measurement for both groups was not significantly different.

DISCUSSION

This randomized controlled trial failed to demonstrate a difference in the primary outcome. HFNP did not show a decrease in respiratory complications when compared with oxygen delivery via a VM in trauma patients with rib fractures.

Of the secondary outcomes there was only found to be a slight decrease in PaCO₂ level in patients receiving HFNP, with a difference of 2 mm Hg between the averages of the groups. The clinical relevance of this is likely to be minimal.

Overall, a low rate of respiratory complications was observed in both groups (6.2% in the HFNP and 6.4% in the VM group). The effective management of rib fractures requires a bundle of care involving appropriate analgesia from acute pain care team and aggressive early interventions of physiotherapy and

Table 2

	High Flow Nasal Prong O ₂ (n=113)	Venturi Mask O ₂ (n=108)	Significance
Primary composite endpoint	7 (6.2%)	7 (6.5%)	P=1.0
Mortality	1 (0.5%)	0	P=1.0
LOS	6 (4,10)	6 (3.5,9)	P=0.71
HDU LOS	2 (2,4)	2 (1,3)	P=0.084
Borg Scale HD 1	4 (2,6)	4 (2,7)	p=0.78
Borg Scale HD 2	3 (2,5)	4.5 (2,6)	P=0.13
Likert Scale HD 1	3 (3,4)	3.5 (3,4)	P=0.63
Likert Scale HD 2	4 (3,5)	4 (3,4)	P=0.47
Respiratory Rate (breaths per minute)	16.5 (SD 3.3)	17 (SD 3.0)	P=0.21
SaO ₂	98 (97, 100)	98 (96, 99.5)	P=0.12
pH	7.38 (SD 0.04)	7.38 (SD 0.36)	P=0.39
paO ₂ (mmHg)	106.3 (SD 30.9)	102.9 (SD 25)	P=0.42
paCO ₂ (mmHg)	43.6 (SD 5.6)	45.5 (SD 6.5)	P=0.032
Peak-flow (metres per second)	245.3 (SD 124)	247.2 (SD 124.5)	P=0.91

COPD, chronic obstructive pulmonary disease.

pulmonary toilet targeting enhancement of the patient’s functional capacity.^{4 25}

There are no existing studies examining the optimal method of oxygen supplementation for patients with rib fractures. A previous systemic review analyzing nine studies concluded that in appropriately chosen patients early use of NIV in patients with blunt chest trauma might decrease respiratory complications and prevent intubation.^{26 27} HFNP O₂ failed to show benefit in the prevention of respiratory complications over conventional O₂ therapy in high-risk respiratory patients with abdominal surgery.^{27 28}

There may be a theoretical benefit with the use of HFNP O₂, with increased positive pressure, and humidified oxygen promoting expectoration of secretions. The results of our study suggest that these theoretical benefits may not translate to a clinically significant effect.

It was also hypothesized that the HFNP system would be more comfortable for patients, as only nasal cannulae were required as compared with a mask. However, again, our results would suggest that patients tolerate both systems equally well.

In the setting of modern healthcare, fiscal discipline is required to counter the ever-increasing introduction of technological advancements. Although a formal cost-benefit analysis was not performed, there is a cost difference between the HFNP O₂ system and the VM system (\$A92.25 vs. \$A1.90; approximate at time of writing). The extra costs associated to HFNP are attributed with the disposable items of tubing, humidification system, water for irrigation and the HFNPs of the HFNP devices. VMs are cheaply manufactured and sold.

LIMITATIONS

Power calculations were based on a higher incidence of respiratory deterioration. There was an unexpectedly lower incidence of respiratory deterioration in this study than the incidence used for power calculation.

The study was not blinded to either patients or the treatment team, which may have introduced bias with the decision to escalate therapy. However, the secondary outcomes do not support any significant differences between the groups. This study was also performed in an urban tertiary trauma hospital, hence might not be applicable to smaller centers.

CONCLUSION

Oxygen supplementation with HFNP O₂ compared with VM oxygen was not shown to be more effective for oxygen supplementation to decrease respiratory complications in trauma patients with rib fractures and high-risk features for respiratory deterioration. There should be consideration for further research to determine if there are any particular groups which may benefit from particular oxygen supplementation systems.

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REFERENCES

- McGillicuddy D, Rosen P. Diagnostic dilemmas and current controversies in blunt chest trauma. *Emerg Med Clin North Am* 2007;25:695–711.
- Easter A. Management of patients with multiple rib fractures. *Am J Crit Care* 2001;10:320–7.
- Sharma OP, Oswanski MF, Jolly S, Lauer SK, Dressel R, Stombaugh HA. Perils of rib fractures. *Am Surg* 2008;74:310–4.
- Witt CE, Bulger EM. Comprehensive approach to the management of the patient with multiple rib fractures: a review and introduction of a bundled rib fracture management protocol. *Trauma Surg Acute Care Open* 2017;2:e000064.
- Sirmali M, Türüt H, Topçu S, Gülhan E, Yazici U, Kaya S, Taştepe I. A comprehensive analysis of traumatic rib fractures: morbidity, mortality and management. *Eur J Cardiothorac Surg* 2003;24:133–8.
- Holcomb JB, McMullin NR, Kozar RA, Lygas MH, Moore FA. Morbidity from rib fractures increases after age 45. *J Am Coll Surg* 2003;196:549–55.
- Flagel BT, Luchette FA, Reed RL, Esposito TJ, Davis KA, Santaniello JM, Gamelli RL. Half-a-dozen ribs: the breakpoint for mortality. *Surgery* 2005;138:717–25.
- Bulger EM, Arneson MA, Mock CN, Jurkovich GJ. Rib fractures in the elderly. *J Trauma* 2000;48:1040–7.
- Karmakar MK, Ho AM-H. Acute pain management of patients with multiple fractured ribs. *J Trauma* 2003;54:615–25.
- Papazian L, Corley A, Hess D, Fraser JF, Frat J-P, Guitton C, Jaber S, Maggiore SM, Nava S, Rello J, et al. Use of high-flow nasal cannula oxygenation in ICU adults: a narrative review. *Intensive Care Med* 2016;42:1336–49.
- May L, Hillermann C, Patil S. Rib fracture management. *BJA Educ* 2016;16:26–32.
- Todd SR, McNally MM, Holcomb JB, Kozar RA, Kao LS, Gonzalez EA, Cocanour CS, Vercruyse GA, Lygas MH, Brasseaux BK, et al. A multidisciplinary clinical pathway decreases rib fracture-associated infectious morbidity and mortality in high-risk trauma patients. *Am J Surg* 2006;192:806–11.
- Helviz Y, Einav S. A systematic review of the high-flow nasal cannula for adult patients. *Crit Care* 2018;22:71.
- Nishimura M. High-Flow nasal cannula oxygen therapy in adults. *J Intensive Care* 2015;3:15.
- Sztrymf B, Messika J, Bertrand F, Hurel D, Leon R, Dreyfuss D, Ricard J-D. Beneficial effects of humidified high flow nasal oxygen in critical care patients: a prospective pilot study. *Intensive Care Med* 2011;37:1780–6.
- Dysart K, Miller TL, Wolfson MR, Shaffer TH. Research in high flow therapy: mechanisms of action. *Respir Med* 2009;103:1400–5.
- Ashraf-Kashani N, Kumar R. High-Flow nasal oxygen therapy. *BJA Educ* 2017;17:63–7.
- Nishimura M. High-Flow nasal cannula oxygen therapy in adults: physiological benefits, indication, clinical benefits, and adverse effects. *Respir Care* 2016;61:529–41.
- Lodeserto FJ, Lettich TM, Rezaie SR. High-Flow nasal cannula: mechanisms of action and adult and pediatric indications. *Cureus* 2018;10:e3639.
- Duggal A, Perez P, Golan E, Tremblay L, Sinuff T. Safety and efficacy of noninvasive ventilation in patients with blunt chest trauma: a systematic review. *Crit Care* 2013;17:4.
- Joshi A, Kale S, Chandel S, Pal D. Likert scale: explored and explained. *Br J Appl Sci Technol* 2015;7:396–403.
- Burns and Groveln. Collecting and managing data. In: Gary JR, Grove SK, *Burns and Grove: the practice of nursing research. appraisal, synthesis and generation of evidence*. St Louis: Elsevier, 2017:411–4.
- Bausewein C, Farquhar M, Booth S, Gysels M, Higginson IJ. Measurement of breathlessness in advanced disease: a systematic review. *Respir Med* 2007;101:399–410.
- Anonymous. Respiratory investigations. *Oxford Handbook of respiratory nursing*. Oxford: Oxford University Press, 2009:110.
- Martin TJ, Eltorai AS, Dunn R, Varone A, Joyce MF, Kheirbek T, Adams C, Daniels AH, Eltorai AEM. Clinical management of rib fractures and methods for prevention of pulmonary complications: a review. *Injury* 2019;50:1159–65.
- Waldau T, Larsen VH, Bonde J. Evaluation of five oxygen delivery devices in spontaneously breathing subjects by oxygraphy. *Anaesthesia* 1998;53:256–63.
- Bell N, Hutchinson CL, Green TC, Rogan E, Bein KJ, Dinh MM. Randomised control trial of humidified high flow nasal cannulae versus standard oxygen in the emergency department. *Emerg Med Australas* 2015;27:537–41.
- Drake MG. High-Flow nasal cannula oxygen in adults: an evidence-based assessment. *Ann Am Thorac Soc* 2018;15:145–55.