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CLINICAL REPORT

The use of inhaled nitric oxide and prone position in an ARDS patient with severe traumatic brain injury during spine stabilization

Paolo Gritti · Luigi Andrea Lanterna · Mariachiara Re · Svetlana Martchenko · Paola Olivotto · Carlo Brembilla · Cristina Agostinis · Guido Paganoni · Ferdinando Luca Lorini

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Abstract The use of inhaled nitric oxide in patients with traumatic brain injury, intracranial hypertension, and acute respiratory distress syndrome (ARDS) has been reported in an intensive care unit setting only in a few case reports. The use of the prone position for patients with traumatic brain injury and lung impairment has been reported only in selected cases. Here we report our experience with the use of both inhaled nitric oxide and the prone position together in the operating room in a patient with head injury and ARDS who underwent column stabilization.

Keywords Inhaled nitric oxide · Prone position · ARDS · Traumatic brain injury

P. Gritti (✉) · M. Re · S. Martchenko · P. Olivotto · G. Paganoni
Anaesthesia and Intensive Care IV, Department of Anaesthesia, Ospedali Riuniti di Bergamo, Largo Barozzi no. 1, Bergamo, Italy
e-mail: grittip@libero.it

L. A. Lanterna · C. Brembilla
Neurosurgery, Department of Neuroscience, Ospedali Riuniti di Bergamo, Largo Barozzi no. 1, Bergamo, Italy

C. Agostinis
Department of Neuroradiology, Ospedali Riuniti di Bergamo, Largo Barozzi no. 1, Bergamo, Italy

F. L. Lorini
Department of Anaesthesia, Ospedali Riuniti di Bergamo, Largo Barozzi no. 1, Bergamo, Italy

Introduction

In patients with severe polytrauma, lung impairment can be derived from a direct injury, through inhalation, through ventilator-associated pneumonia, or through neurogenic pulmonary edema [1–3]. Moreover, when a polytrauma patient also shows fractures of the thoracolumbar spine, the forced supine position may worsen the lung function [4]. However, acute lung injury (ALI) and acute respiratory distress syndrome (ARDS) can occur in 20–25 % of patients with isolated brain injury and these factors are independent predictors of poor outcome [3].

Inhaled nitric oxide (NO) is a selective pulmonary vasodilator that decreases pulmonary resistance and improves ventilation-perfusion matching and oxygenation in patients with pulmonary hypertension and in adults with ALI or ARDS [5]. The use of the prone position is another well-established method to improve oxygenation, but it is rarely considered in the neurosurgical intensive care unit (ICU) owing to the risk of intracranial hypertension [6].

Both of these techniques require days or weeks of intensive treatment where it is almost impossible to move these extremely ill patients out of the ICU for diagnostic or surgical procedures. However, further complications, such as spine fracture, require prompt surgical treatment [7].

Here we report our experience with the use of both NO and pronation in a head-injury patient who underwent column stabilization.

Case report

A 37-year-old male patient was admitted to our Emergency Department with multiple injuries sustained following an accidental fall from a height of 10 m. The patient was

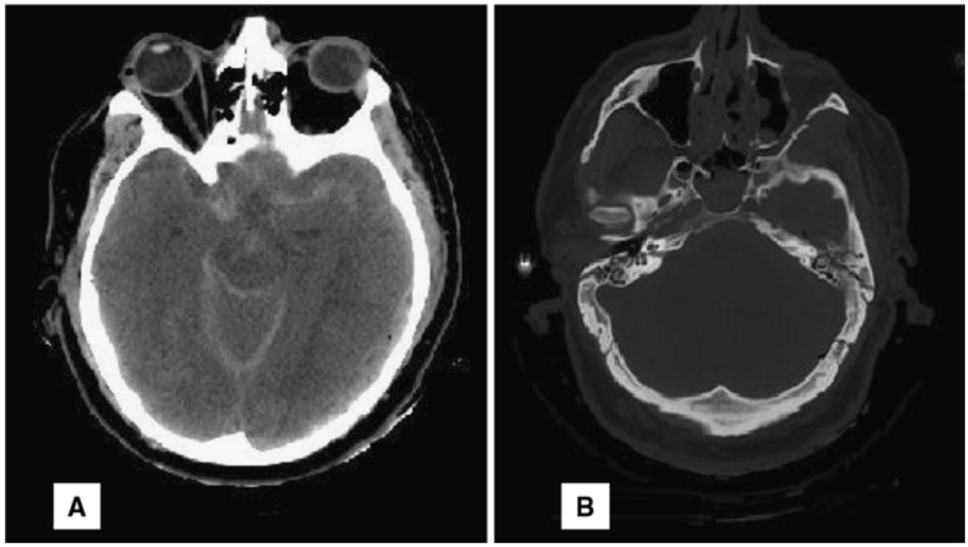

Fig. 1 Diffuse subarachnoid hemorrhage and epidural hematoma of 3–4 mm in the left temporal-occipital area (**a**). Note the multiple skull fractures (**b**)

found to be mydriatic in respiratory arrest, so he was intubated at the scene of the accident and when the main vital parameters were stabilized, transported to the Emergency Department of our hospital. He arrived with a blood pressure of 95/55 mmHg, heart rate of 106 beats per min, and peripheral oxygen saturation (SpO_2) 100 % on fraction of inspired oxygen (FiO_2) 1.0. The Glasgow coma scale (GCS) was 3 while his pupils were round and reactive to light. A head computed tomography (CT) scan demonstrated diffuse subarachnoidal hemorrhage, multiple skull fractures, and an epidural hematoma of 3–4 mm in the left temporal-occipital area that was determined not to need surgical evacuation because of its size (Fig. 1a, b). The chest and column roentgenogram revealed a fracture of the twelfth left rib and a lumbar vertebral fracture with a fragment of bone projecting into the spinal canal which required the patient to be placed in a forced supine position.

The patient was transferred to the ICU where an intracranial pressure monitor was inserted. Within a few hours the patient's respiratory condition deteriorated with the development of severe ARDS (Fig. 2). The next day arterial blood-gas-analysis (ABG) showed a partial pressure of arterial oxygen (PaO_2) of 58 mmHg on FiO_2 1.0. The patient was treated with inhaled NO administered at 10 ppm from a KOMIS® (Flow-meter, Levate, Bergamo, Italy) and a Servo-i® ventilator (version-1.2; Maquet, Bridgewater, NJ, USA) with an increase of the PaO_2/FiO_2 ratio from 58 to 144 in <3 h (Fig. 3a).

Over the next days the patient's intracranial pressure rose from 10–15 to 25 mmHg and sedation and osmotic therapy (20 % mannitol 2 ml/kg) were administered to maintain cerebral perfusion pressure at more than 60 mmHg. However, the CT scans of the head showed no indication for neurosurgical intervention.

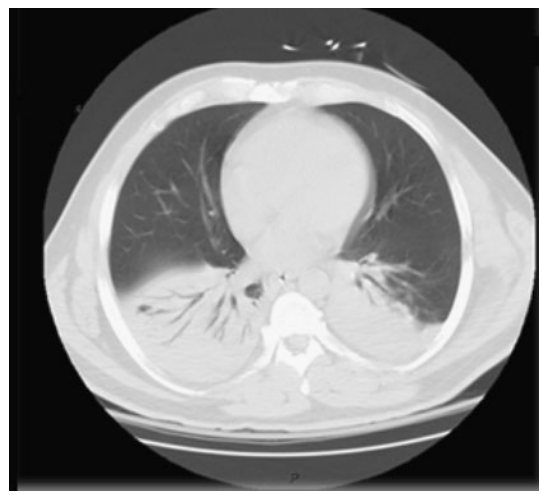

Fig. 2 Early computed tomography (CT) scan of the chest that shows posterior lung regions preferentially infiltrated, consolidated, or collapsed

Intraoperative management

The increase of intracranial pressure was probably due to the forced supine position and complicated by the pulmonary conditions; therefore, on the eighth day of recovery it was decided to submit the patient to a surgical stabilization of the column. The patient was transferred to the operating room without being disconnected from the NO inhalation system, which was also transferred to the operating room. The patient was ventilated using a pressure-regulated volume control mode with a tidal volume of 6 ml/kg adjusted to maintain a peak inspiratory pressure set to no more than 30 cm of water. Respiratory rates were adjusted in an attempt to maintain arterial carbon dioxide tension at 30–35 mmHg, and inspiratory time was set to prevent air trapping (I: E ratio at 1: 1.8). Positive

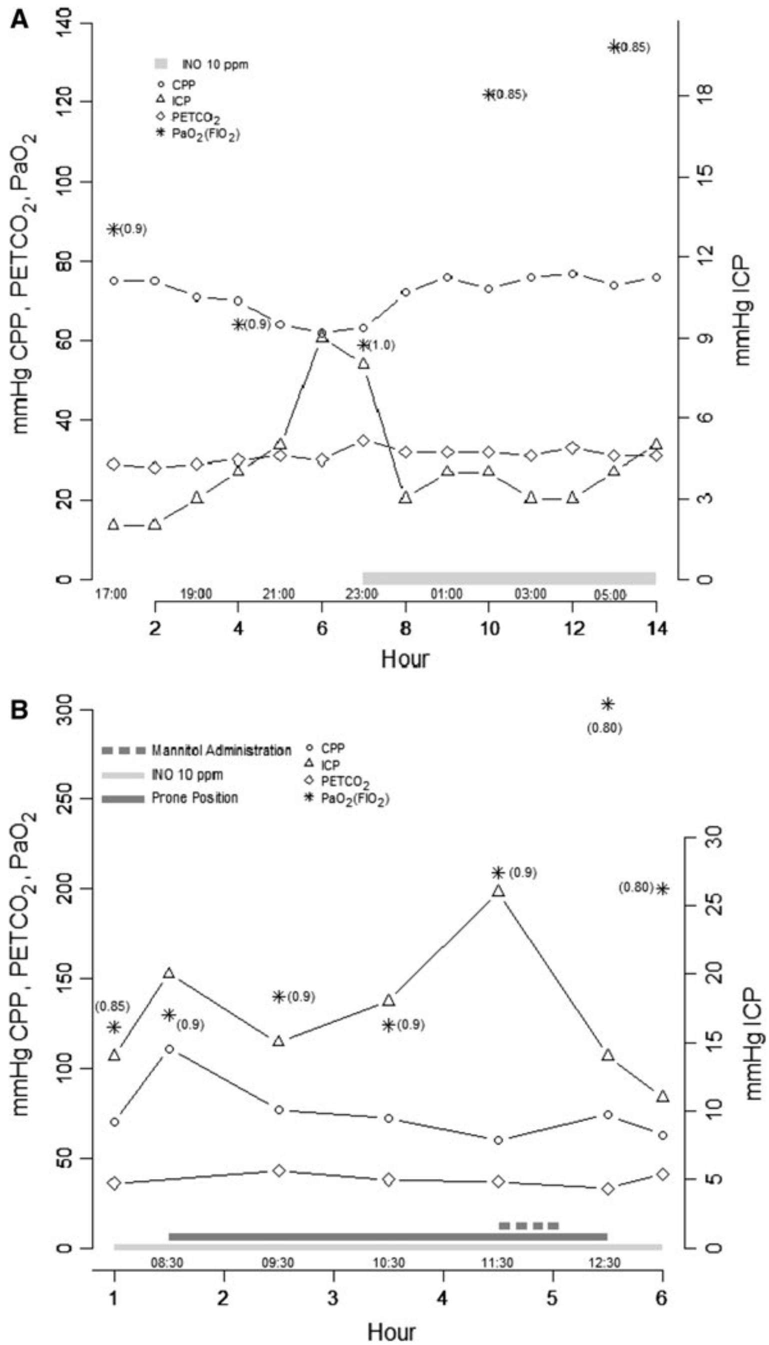

Fig. 3 **a** Data during the start of the inhaled nitric oxide (*NO*) administration. Note the improvement of the intracranial pressure and oxygenation after adjunct therapy of inhaled nitric oxide. **b** Patient vital sign data registered preoperatively and in the operating theater during inhaled nitric oxide administration while in the prone position. Note the improvement of oxygenation after prone positioning and the partial decrease in ICP after mannitol administration. *INO* inhaled nitric oxide, *CPP* cerebral perfusion pressure, *ICP* intracranial pressure, $PETCO_2$ partial pressure of end-tidal carbon dioxide, PaO_2 partial pressure of arterial oxygen, FiO_2 fraction of inspired oxygen

end-expiratory pressure was set at 10 to 12 cmH_2O to provide the best oxygen delivery with an FiO_2 of <90 %, while inhaled NO was continuously administered at 10 ppm. In the operating room the patient was prone, with a disposable head cushion placed to protect his face and head (Disposa-View™; GE Healthcare, Lineside Industrial Estate, Littlehampton, UK).

To avoid interaction between inhaled NO and any other gas, total intravenous anesthesia was applied. Propofol, fentanil, and vecuronium were continuously infused.

The operation lasted for 4 h, during which the oxygenation of the patient improved owing to the prone position (Fig. 3b). The intracranial pressure range slightly worsened, from 15 to 25 mmHg, but was easily controlled with one administration of 150 ml of 20 % mannitol (Fig. 3b; Table 1). The patient was transfused with 3 U of blood and 2 U of fresh frozen plasma. After the surgery the patient was returned to the ICU using the same ventilatory system.

Over the next days, the patient was moved to the prone position every 8–12 h, with inhaled NO being continuously

Table 1 Patient vital sign data registered perioperatively during inhaled nitric oxide administration and pronation

Time	8:00	8:30	9:30	10:30	11:30	12:30	13:00
Position	Supine	Prone	Prone	Prone	Prone	Prone	Supine
Inhaled NO (ppm)	10	10	10	10	10	10	10
Tidal volume (ml)	600	600	620	650	650	700	630
Minute ventilation (l)	13.8	13.8	12	12.8	12.8	11.9	12
RR (no./min)	23	23	18	18	18	17	19
PAwP (cmH_2O)		28	30	31	31		
MAwP (cmH_2O)		15	19	18	18		
PEEP (cmH_2O)	12	12	12	12	12	12	12
pH	7.37	7.36	7.38	7.42	7.44	7.45	7.4
FiO_2	0.85	0.90	0.90	0.90	0.90	0.80	0.80
PaO_2 (mmHg)	123	130	140	124	209	303	200
PaO_2/FiO_2	145	144	155	137	232	378	250
$PaCO_2$ (mmHg)	36		43	38	37	33	41
ICP (mmHg)	14	20	15	18	26	14	11
CPP (mmHg)	70	111	77	72	60	74	63
Infusion (U or ml)				3 RBC 2 FFP	150 Mannitol 20 %		

NO nitric oxide, *RR* respiratory rate, *PAwP* peak airway pressure, *MAwP* mean airway pressure, *CPP* cerebral perfusion pressure, *PEEP* positive end-expiratory pressure, *ICP* intracranial pressure, *PaO$_2$* partial pressure of arterial oxygen, *PaCO$_2$* partial pressure of arterial carbon dioxide, *FiO$_2$* fraction of inspired oxygen, *FFP* fresh frozen plasma, *RBC* red blood cells

administered at 10–20 ppm, showing a constant improvement of ABG analysis. Intracranial pressure and cerebral perfusion pressure slightly deteriorated during the pronation but they were easily controlled with osmotic therapy, and in order to facilitate venous drainage from the head, the bed was raised to 15°–20°. The patient was successfully weaned off the inhaled NO and the ventilator support after 22 and 43 days, respectively, and the patient was finally transferred to a rehabilitation facility with a GCS score of 14 four months after being weaned off the ventilator support.

Discussion

ARDS patients require protective ventilator strategies that allow a certain degree of hypercapnia and the use of inhaled NO and pronation to improve oxygenation [5, 6, 8]. However, patients at risk of intracranial hypertension owing to severe head injury need tight CO_2 control, and mechanical ventilation is the main supportive therapy used to control carbon dioxide production [9]. In head-injury patients with ALI/ARDS these therapeutic measures may be in opposition, and the best therapy to follow presents a challenge for the anesthesiologist called to manage an emergency surgical procedure.

Our case highlights and reconfirms some concepts that are already known, and offers new ones. Firstly, the use of inhaled NO improves the oxygenation of the patient without adverse effects on intracranial pressure and cerebral perfusion pressure, in accord with literature reports, suggesting a benefit through improved physiological parameters and a decrease in biochemical markers of inflammation and brain injury [10–12]. The lack of adverse cerebrovascular effects of inhaled NO in our patient may be explained by NO being rapidly metabolized before it reaches the cerebral circulation [5, 10–12].

Moreover, our experience demonstrates that it is possible to perform easy transportation and use of inhaled NO in the operating room in patients who could not be disconnected from NO without becoming hypoxic. Flaatten et al. [13] showed that this was possible with the help of a particular device (Noresc 1503®; DanSjo Medical, Sweden). Our transport required an inhaled NO system that did not need any electrical connection. The use of environmental monitoring and equipment to absorb NO during transport in the operating room was deemed unnecessary. The environmental concentrations of NO and nitrogen dioxide should not exceed a time-weighted average of 25 and 2 ppm, respectively, over an 8-h period. Such levels would not accumulate in a well-ventilated room such as our operating room (10–12 air changes per hour) [8]. Finally, all halogenated volatile anesthetics are known to interfere with those reactions involving NO synthesis and NO receptor activation. To avoid any adverse effects we used only intravenous anesthetic drugs [14].

The supine 30° head-up posture is recommended to achieve the lowest intracranial pressure in head-injury patients [9]. The column fracture in our patient required the forced supine position, resulting in limited diaphragmatic excursion and drainage of bronchial secretions. This poor respiratory function and limited cerebral venous drainage increased the risk of intracranial hypertension [4, 7, 9]. Current literature evidence states that early surgical stabilization of the spine leads to fewer pulmonary complications [7]. Although pronation of the patient alters the drainage of blood from cerebral veins and could worsen the cerebral perfusion pressure, in their study Nekludov et al. [15] demonstrated improved oxygenation, slightly increased intracranial pressure, and a moderate increase of the mean arterial pressure in patients with head injury and ARDS during the treatment in the prone position. This evidence suggests that in selected ARDS patients the beneficial effects of the prone position on oxygenation can outweigh the hazardous effect on intracranial pressure [15].

For these reasons we chose spine surgery stabilization using NO inhalation combined with the prone position. Improvement in the ABG analysis during the operation with only a slight worsening of cerebral perfusion pressure encouraged us to place the patient in the prone position also during the days following the operation. However, owing to the risk of increasing the intracranial pressure in patients with head injury, intracranial pressure and cerebral perfusion pressure monitoring is recommended during the pronation of such patients.

Our experience, being with a single patient, does not allow us to reach definitive conclusions, although it suggests that both inhaled NO and the prone position may be useful as additional short-term adjuncts to respiratory support in patients with severe head injury. However, to validate the association of both inhaled NO and pronation and to add more clarity to the selection of head injury patients to whom these adjuncts can be used, further rigorously designed experimental and clinical studies are necessary.

Conflict of interest None.

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