An exploration of oxygenation indices in proned patients

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Introduction

The Acute Respiratory Distress Syndrome (ARDS) was initially identified as a clinical entity in the 1960s[1]. ARDS consists of diffuse alveolar damage due to the activation of alveolar macrophages to release pro-inflammatory cytokines[2] that attract neutrophils to the lungs where they damage the alveolar and capillary epithelium by release of toxic mediators. This leads to the alveoli being filled with bloody, proteinaceous fluid. Consequently, the surfactant can no longer support the alveoli[3]. The end result is that these damaged alveoli lead to impaired gas exchange, which is the pathophysiolgic hallmark of ARDS.

Patients with certain clinical conditions are at higher risk for developing ARDS. These can broadly be grouped into direct lung injury risk factors like pneumonia, aspiration, pulmonary contusion, inhalational injury, near drowning etc. (heretofore referred to as 'ARDSp') and indirect lung injury risk factors such as sepsis, non-thoracic injuries/hemorrhagic shock, pancreatitis, burns, drugs/toxins, blood transfusions, cardiopulmonary bypass and reperfusion injury after lung transplant or embolectomy (which will now be referred to as 'ARDSexp')[4]. Severe lung injury secondary to Covid-19 has certain unique features, and has been termed 'C-ARDS'[5].

To date, there are no specific drugs or therapies available to directly treat/prevent ARDS. Mechanical ventilation that aims to protect injured lungs and minimize Ventilator Induced Lung Injury (VILI), and management of refractory hypoxaemia, are the keystones in supportive management of ARDS[6]. Part of the above can include placing a patient in the prone (i.e. 'face down') position. This was first described as a therapy for ARDS in the 1970s[7]. The mechanism by which prone positioning improves oxygenation is multifactorial. It reduces the ventral to dorsal transpulmonary pressure difference, ventilation-perfusion mismatch and lung compression[8,9]. Other potential physiological effects of prone positioning include a decrease in proinflammatory cytokines and improvement in right ventricle dysfunction by preserving pulmonary circulation[10].

The first prospective randomized control trial (known as the 'PROSEVA' trial) that showed a mortality benefit from prolonged prone positioning was conducted in France and published in 2013[11]. Prone positioning for at least 12 to 16 hours per day, while administering low tidal volumes (4-6ml/kg of ideal body weight), is now strongly recommended in ventilated patients with severe ARDS[12].

Many questions regarding the utility and efficacy of the prone position remain. An important issue lies in identifying patients who, although they fit the criteria to undergo prone positioning, are unlikely to receive a mortality benefit and in whom other therapies may be effective[13].

Population

Initial selection

This section shows details of the population involved in this study. The data was gathered by interrogating the Electronic Health Record system used in the Intensive Care Unit (ICU) of University Hospital Galway (UHG). The system was queried to return all patients on record whp fulfilled the following criteria:

- over 18 years of age
- invasively ventilated
- placed in the prone position whilst invasively ventilated

Study population

A total of 133 records were isolated from the servers. These records date from between 14/07/2013 and 20/03/2022. They consisted of patients who had been placed in the prone position secondary to a pulmonary insult (ARDSp), and extrapulmonary insult (ARDSexp), and Covid-19 (C-ARDS). Patients in the dataset were proned between 1 and 13 times. Full details of these demographics can be seen overleaf in Table 01.

Table 1: Study population demographics

Characteristic	**Overall**, N = 133	**ARDSp**, N = 73	**Covid_19**, N = 51	**ARDSexp**, N = 5	**Unknown**, N = 4
Gender					
f	45 (34%)	28 (38%)	15 (29%)	1 (20%)	1 (25%)
m	88 (66%)	45 (62%)	36 (71%)	4 (80%)	3 (75%)
Age (years)	58 (15)	57 (16)	60 (13)	52 (13)	64 (14)
Height (cm)	169 (13)	167 (16)	171 (10)	178 (12)	172 (9)
Not recorded	27	17	9	1	0
Weight (kg)	86 (21)	81 (21)	93 (21)	85 (12)	94 (14)
Admitting location					
cath lab	1 (0.8%)	1 (1.4%)	0 (0%)	0 (0%)	0 (0%)
ccu	3 (2.3%)	3 (4.1%)	0 (0%)	0 (0%)	0 (0%)
ed	27 (20%)	17 (23%)	8 (16%)	1 (20%)	1 (25%)
guh_ward	58 (44%)	31 (42%)	25 (49%)	2 (40%)	0 (0%)
theatre (elective)	3 (2.3%)	3 (4.1%)	0 (0%)	0 (0%)	0 (0%)
theatre (emergency)	4 (3.0%)	3 (4.1%)	0 (0%)	1 (20%)	0 (0%)
transfer	37 (28%)	15 (21%)	18 (35%)	1 (20%)	3 (75%)
LOS (days)	19 (18)	21 (22)	18 (13)	14 (7)	8 (3)
Apache II	19 (8)	21 (7)	14 (5)	27 (10)	31 (11)
Proning sessions	3 (2)	2 (2)	3 (2)	1 (0)	2 (1)
Outcome					
dc	72 (54%)	39 (53%)	29 (57%)	3 (60%)	1 (25%)
rip	61 (46%)	34 (47%)	22 (43%)	2 (40%)	3 (75%)
BMI	31 (8)	30 (8)	32 (7)	28 (3)	31 (3)
Not recorded	27	17	9	1	0

Data gathered around prone-positioning

For each patient, values relating to ventilation and oxygenation were isolated around every session of prone positioning that took place whilst the patient was invasively ventilated. The following values were recorded:

Ventilation

- Fraction of inspired oxygen (FiO_2)
- Minute Volume (MV), measured in L/min
- Positive End-Expiratory Pressure (PEEP), measured in cmH_2O
- Peak Inspiratory Pressure (PIP), measured in cmH_2O
- Mean Airway Pressure (P_{aw}), measured in cmH_2O

Oxygenation

- peripheral oxygen saturation (SpO_2), recorded using bedside pulse oximetry
- saturation of oxygen (SaO_2), recorded from arterial blood gas
- partial pressure of oxygen (PaO_2), recorded from arterial blood gas

Other

- partial pressure of carbon dioxide ($PaCO_2$), recorded from arterial blood gas
- haemoglobin concentration (g/dL), recorded from arterial blood gas

Oxygenation indices

Overview

The following indices of oxygenation will be examined. Some have been recorded directly from monitoring equipment to which the patient was attached in ICU, and some have been calculated. The indexes are outlined below. Summary statistics and an overview of the distribution for each variable follows.

The following recorded *directly*:

- SpO_2
- SaO_2
- PaO_2

The following were *calculated* from recorded values:

- P/F ratio
- Ventilatory ratio
- Oxygenation index
- Oxygenation factor
- A-a O_2 gradient
- Arterial O_2 content (CaO_2)

P/F ratio

PaO_2/FiO_2 ratio is the ratio of arterial oxygen partial pressure to fractional inspired oxygen. The equation is:

$$P/F\ ratio = \frac{PaO_2}{FiO_2}$$

Ventilatory ratio

$$Ventilatory\ ratio = \frac{MV \times Pa_{CO_2}}{PBW \times 100 \times 5}$$

Oxygenation index

$$Oxygenation\ index = \frac{FiO_2 \times P_{AW}}{PaO_2}$$

Oxygenation factor

$$Oxygenation\ factor = \frac{PF\ ratio}{P_{AW}}$$

A-a O_2 gradient

$$A-a\ gradient = [FiO_2 \times (P_{atm} - P_{H_2O}) - \frac{Pa_{CO_2}}{0.8}] - Pa_{O_2}$$

Arterial O_2 content

$$Ca_{O_2} = (1.34 \times [Hb] \times Sp_{O_2}) + (0.0225 \times Pa_{O_2})$$

Explorations & Comparisons

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