



COMMENT

Helmet continuous positive airway pressure and prone positioning: A proposal for an early management of COVID-19 patients



F. Longhini^{a,*}, A. Bruni^a, E. Garofalo^a, P. Navalesi^b, G. Grasselli^{c,d}, R. Cosentini^e, G. Foti^{f,g}, A. Mattei^h, M. Ippolitoⁱ, G. Accursoⁱ, F. Vitaleⁱ, A. Cortegianiⁱ, C. Gregorettiⁱ

^a Anesthesia and Intensive Care, Department of Medical and Surgical Sciences, Magna Graecia University, Catanzaro, Italy

^b Anesthesia and Intensive Care, Padua Hospital, Department of Medicine – DIMED, University of Padua, Italy

^c Department of Pathophysiology and Transplantation, University of Milan, Italy

^d Dipartimento di Anestesia, Rianimazione ed Emergenza-Urgenza, Fondazione IRCCS Ca' Granda Ospedale Maggiore Policlinico, Milan, Italy

^e Emergency Medicine Department, ASST Papa Giovanni XIII, Bergamo, Italy

^f School of Medicine and Surgery, University of Milano-Bicocca, Monza, Italy

^g Department of Anesthesia and Intensive Care Medicine, ASST Monza, Monza, Italy

^h Department of Pneumology, A.O.U. Città della Salute e della Scienza of Turin, Turin, Italy

ⁱ Department of Surgical, Oncological and Oral Science (Di.Chir.On.S.), Section of Anaesthesia, Analgesia, Intensive Care and Emergency, Policlinico Paolo Giaccone, University of Palermo, Italy

Introduction

In late December 2019, clusters of patients with interstitial pneumonia of unknown cause were reported by some local health facilities in Wuhan (China). The Chinese Centre for Disease Control conducted an epidemiologic and etiologic investigation, leading to the identification of a novel coronavirus (SARS-CoV-2).^{1,2} On March 11th, the World Health Organization (WHO) declared the novel coronavirus disease (COVID-19) a pandemic. In the area of Wuhan, COVID-19 mainly affected male patients (around 60%), with a median age of about 50 years; 40% of patients developed Acute Respiratory Distress Syndrome (ARDS) 5% requiring intensive care. The mortality rate was around 2%.^{3,4} However, Grasselli et al. found that the mortality was 26% in ICU. The death rate was higher among those who were older.⁵

In a more recent report from Italy including 22512 patients, COVID-19 has infected 2026 healthcare workers, with a total case fatality rate of 7.2%. Patients were predominantly older than 60 years, 46.1% had mild severity, while 24.9% severe disease.⁶

To date (April 16th) the cases are 1991562 with more than 130 000 deaths.⁷ In a certain percentage of patients, COVID-19 is a viral interstitial pneumonia⁸ characterized by fever, dry cough, dyspnoea, and bilateral ground-glass opacities,⁹ with about 67% of patients evolving to a severe pneumonia.^{10,11}

However, preliminary observations reported that COVID-19 patients, compared to conventional ARDS, are characterized by moderate to severe hypoxaemia despite a relatively high pulmonary compliance.^{12,13} A potential mechanism may be loss of hypoxic vasoconstriction, explaining the observed severe hypoxaemia and the effect of very high levels of positive end-expiratory pressure (PEEP) on oxygenation not depending on lung recruitment.¹³ High levels of PEEP may adjust redistribution of perfusion diverting flow towards high ventilation-perfusion (Va/Q) areas increasing arterial

* Corresponding author.

E-mail address: longhini.federico@gmail.com (F. Longhini).

oxygen tension (PaO_2); however, over-distension of the healthy lung areas and an increased right cardiac afterload is possible.¹³

In patients with mild to moderate ARDS, with a PaO_2 to inspired oxygen fraction ($\text{PaO}_2/\text{FiO}_2$) >150 , different modalities of non-invasive respiratory support (NIRS) might be attempted in order to avoid intubation.^{14,15} However, NIRS could potentially lead to intubation delay and cause a self-inflicted lung-injury (SILI),¹⁶ due to the high transpulmonary pressures. SILI in turn would lead to a severe decrease in lung compliance.¹⁷ Continuous Positive Airway Pressure (CPAP) is a form of NIRS during which a fixed level of PEEP is applied to the airways, while the entire work of breathing is generated by the patient's respiratory muscles (i.e. no pressure assist is provided during inspiration). This would reduce the likelihood of generating high transpulmonary pressure and tidal volume compared to non-invasive intermittent positive pressure ventilation.¹⁸

Due to the enormous number of COVID-19 patients with acute respiratory failure and to the shortage of ICU beds and ventilators, helmet CPAP (hCPAP) is widely used in Italy.^{5,19}

In particular, in a scenario of a discrepancy between facilities and a large number of casualties, as with COVID-19 pandemic, the application of hCPAP might be useful as an 'easy to perform' supportive strategy.

Prone position sessions may adjust pulmonary perfusion diverting flow towards high Va/Q areas, and allowing a redistribution of aerated and non-aerated areas whenever present.^{20,21} Furthermore, as opposed to non-invasive intermittent positive pressure, hCPAP does not necessarily need a ventilator (potentially in short supply in case of mass casualties) and it is not affected by patient-ventilator asynchrony, a determinant of discomfort and treatment failure.²²⁻²⁴

The hypothesis is that in case of a pandemic, selected COVID-19 patients may benefit from the combination of early hCPAP and prone position sessions, in order to reduce the need for intubation and invasive mechanical ventilation, "buying time" for the disease to heal.

Evaluation of the hypothesis

Prone position

Prone position was first described in 1976 in patients with ARDS.²⁵ First, prone position modifies respiratory mechanics. In particular, the ventral chest wall cannot expand, because it is in contact with the firm surface of the bed.²⁶ In patients with ARDS, the lung weight increases by 4–5 times, pulmonary tissue becomes stiffer and compliance decreases, in association with compression atelectasis.^{26,27} During prone position, decreased chest wall compliance improves the redistribution of lung density from dorsal to ventral areas, and increases lung aeration from ventral to atelectatic dorsal regions, improving gas exchange.²⁸ Nowadays, the application of prone position is recommended in most severely ill patients. Guerin et al. showed that, in patients with severe ARDS, the application of prolonged (17 h) prone position sessions for approximately 4 days reduced the absolute mortality risk by 17% and the relative risk by 50%.²⁹ However, other studies have not shown outcome benefits of prone position.³⁰⁻³³

These differences might be explained by the fact that patients included were not so severely ill, periods of use were shorter and the use of protective ventilation strategies were less strictly enforced.³⁴ Early application of prone position for prolonged (up to 16 h) periods has been also demonstrated to improve the survival rate²⁹ in other clinical settings.

It has been suggested that prone position in COVID-19 patients may lead to overwork of professionals with scarce clinical efficacy in terms of recruitment.¹³ However, preliminary data suggest that COVID-19 patients undergoing CPAP may benefit from this treatment with even the most severe forms of hypoxaemic respiratory failure characterized by a refractory hypoxaemia (i.e. $\text{PaO}_2/\text{FiO}_2 < 150$).⁵

Our hypothesis is that, selected COVID-19 patients may benefit from the combination of early hCPAP at moderate levels of PEEP (i.e. 10 cmH_2O) and prone position, to avoid overdistension of the healthy lung areas thus slowing the progression of the disease and allowing patients to "buy time" to heal. Indeed, in these instances, hCPAP is likely to be effective by keeping the lung open²⁰ and reducing venous admixture by diverting flow towards better high Va/Q areas.²¹

Non-invasive respiratory support

Although life-saving, invasive mechanical ventilation is associated with side effects and complications leading to increased morbidity and mortality. Therefore, alternative strategies have been proposed, especially for those patients with less severe forms of ARDS. Among these strategies, NIRS might play a role in reducing intubation rate.¹⁴ Application of positive pressure to the airway may open collapsed alveoli, increase functional residual capacity and improve the Va/Q match and lung compliance. As a result, oxygenation and respiratory workload improve, with the potential benefit of avoiding intubation and invasive mechanical ventilation.¹⁴ More recently, the combination of non-invasive intermittent positive pressure with prone position was shown to prevent the need for intubation in up to half of the patients with moderate to severe ARDS. In addition, patients failing NIRS and requiring intubation were more severe, as compared to those succeeded.³⁵

The use of CPAP may provide the application of a stable level of positive airway pressure throughout the entire respiratory cycle. Therefore, it may result in effective recruitment of closed alveoli, with an increase in the functional residual capacity and improvement of oxygenation.^{36,37} During NIRS, comfort is one of the determinants of treatment success or failure.³⁸ CPAP may be delivered through different interfaces, such as masks or helmets. Compared to masks, helmets are more comfortable,³⁹ they allow longer continuous application of the treatment and lower complications correlated to the interface (i.e. eye irritation, gastric distension and skin necrosis).³⁹ As during NIRS, comfort is one of the determinants of treatment success or failure^{38,39} it is important to note that unintentional leaks are kept to a minimum during hCPAP.⁴⁰⁻⁴²

The "helmet bundle" in COVID-19 patients has recently been published to optimize treatment.¹⁹

Precautions when using NIRS

It is worth noting that the recent guidelines on the use of NIRS in *de novo* hypoxaemic acute respiratory failure do not provide any recommendation, due to uncertain and conflicting evidence.⁴³ Very recently, the Surviving Sepsis Campaign has provided some guidelines on the management of critically ill COVID-19 patients.⁴⁴ The panel of experts suggested a trial of NIRS, recommending close short-interval monitoring for worsening of respiratory status and early intubation in a controlled setting if worsening occurs,⁴⁴ although the main risk of using NIRS in *de novo* ARF is delay in intubation⁴⁴ with the risk of developing SILI.^{16,17}

NIRS in the era of COVID-19

Non-invasive intermittent positive pressure requires the use of mechanical ventilators, of there is currently a shortage due to the pandemic COVID-19.^{3,6} Furthermore, non-invasive intermittent positive pressure may also worsen patient-ventilator interaction and synchrony, which might be detrimental for patients' comfort, leading to treatment failure.^{22–24} For these reasons, CPAP might be a valid alternative. In addition, the use of an interface such as the helmet may be advantageous, compared to a facial mask.^{45–47} In fact, the helmet improves comfort of the patient, assures prolonged continuous application of the treatment and it is characterized by very low air-leaks,^{40,45–48} limiting the spread of the virus in the environment. Interestingly, when a patient coughs, he/she generates a peak cough flow up to 400 L/min, theoretically creating less contamination for the operators and environment. High flow nasal therapy could be also combined with hCPAP.^{49,50} However, experimental studies of exhaled air dispersion by mannequins have demonstrated greater exhaled air dispersion with conventional low flow nasal cannula at 5 l/min, compared with HFNC.⁵¹ Furthermore, the helmet's ports can be protected with two antimicrobial filters, further reducing air dispersion. This is of utmost importance in cases of infections transmitted by aerosolization, such as COVID-19.⁴¹

Based on these facts, we have hypothesized that, in the current COVID-19 pandemic emergency, an attempt to combine early hCPAP and prone positioning sessions might improve oxygenation in selected patients. Criteria to attempt hCPAP (8–12 cmH₂O) and prone position in fully collaborating symptomatic patients are listed in Table 1. The presence of dyspnoea, as defined by a Borg scale >3,⁵² is not deemed necessary because dyspnoea is not always clinically evident in these patients. Patients with chronic obstructive pulmonary disease or with an arterial partial pressure of carbon dioxide >50 mmHg will be excluded.

Settings for CPAP in prone position

Prone position during hCPAP requires some precautions, in order to avoid discomfort, skin and eyes lesion and treatment failure. First, the use of helmet without armpit braces is preferable, although not mandatory, since in the literature it has been reported to be more comfortable.^{48,53} Another important precaution is to prevent the rigid collar from generating skin lesions by direct pressure on skin

Table 1 Inclusion and exclusion criteria.

Inclusion criteria	Exclusion criteria
Cough, fever, sign of interstitial pneumonia on chest X-Ray, lung ultrasound and/or CT-scan	Chronic obstructive pulmonary disease
History of previous contact with COVID-19 patients	Arterial partial pressure of carbon dioxide >50 mmHg
Patients with a PaO ₂ /FiO ₂ between 200 and 300, while breathing in room air or through Venturi mask measured after 1 h from hospital admission	Pregnancy
Pulse oxymetry (SpO ₂) <95% in room air	Contraindication to CPAP
Dyspnoea, as defined by a Borg scale >3	



Figure 1 The figure shows a patient in prone position receiving hCPAP. One small pillow is positioned under the chest and another one under the head, to raise the head and to leave some free space around the neck.

due to ischaemia or shearing forces and mechanical stress to the neck. Interestingly awake patients during hCPAP may assume prone position with minimal assistance. Fig. 1 shows one patient switched from supine to prone position using hCPAP and continuous tidal volume measurement using a dedicated software built into a turbine driven ventilator.⁵⁴

Consequence of the hypothesis and discussion

This is the first proposal of a study aimed at investigating the possibility of combining hCPAP and prone position in order to avoid deterioration of gas exchange and intubation in patients affected by COVID-19 pneumonia.

The application of early sessions of pronation in patients with mild-to-moderate ARDS might improve gas exchange without further increasing PEEP.^{26,27} This experimental plan has several strengths. First, a thorough literature review and straight-forward protocol definition will guarantee the best possibilities for the intervention. The experimental treatment has notable possibilities of being effective and helpful, in particular in a setting of mass-casualties happening now in Italy and rest of Europe. Second, the ability to limit the

treatment to selected patients may amplify the potential benefits reducing the failure rate. Third, if the combination of hCPAP and prone position reduced the intubation rate, the health care system could improve the allocation of ICU beds, granting better treatment to all patients needing ventilatory assistance.

Furthermore, our preliminary results (Gregoretto et al., unpublished data) from an ongoing pilot study in COVID-19 patients, measuring tidal volume during hCPAP,⁵⁴ showed that a low mean tidal volume coupled with high pulmonary compliance and a low respiratory rate, which suggests that transpulmonary pressure is kept low.

Our hypothesis has also some major limitations. First of all, the real effect of hCPAP from the pathophysiological point of view in this disease is unknown. In healthy patients, CPAP in prone position causes a V_a/Q mismatch for a more uniform ventilation distribution, despite a higher perfusion in dependent parts of the lung.^{33,55} CPAP may increase alveolar pressures and resistance in small vessels of the lungs (zone 1)⁵⁶ especially in nondependent lung regions, explaining the higher perfusion in dependent parts when the subject is prone. This finding suggests the redistribution of perfusion could improve oxygenation in patients lacking hypoxic vasoconstriction. Second, inclusion criteria for this treatment are untested; in addition, time in prone position from our preliminary data is shorter than in sedated patients. Third, strict monitoring by trained personnel, in a step-down unit or in a monitored unit, would be required to early identify a treatment failure and avoid any intubation delay. Lastly, patient's tolerance may play a fundamental role in the treatment. In addition, the lack of patient-ventilator asynchronies during CPAP together with the use of the "helmet bundle" should ameliorate tolerance.⁴¹

In conclusion, if our hypothesis is valid, physicians may reduce the need for endotracheal intubation and invasive mechanical ventilation, shortening the hospital length of stay and improving survival rates. Furthermore, the need for ICU beds may be reduced, in favour of sub-intensive beds. This setting does not exclude the need of implementation in areas where prompt intubation can be easily performed. In addition, this strategy may also be an adjunctive tool for those patients who are not recommended for endotracheal intubation and care is limited to hCPAP as "ceiling of treatment".

Otherwise, patients treated with hCPAP presenting with clinical signs of excessive inspiratory effort, should be promptly intubated to avoid too injurious transpulmonary pressure leading to SILI.¹⁶

Conflicts of interest

Dr. Navalesi's research laboratory has received equipment and grants from Maquet Critical Care, Draeger and Intersurgical S.p.A. He also received honoraria/speaking fees from Maquet Critical Care, Orionpharma, Philips, Resmed, MSD and Novartis. Dr. Navalesi contributed to the development of the helmet Next, whose licence for patent belongs to Intersurgical S.P.A., and receives royalties for that invention. Dr. Longhini and Dr. Navalesi contributed to the development of a new device, whose patent is in progress (European Patent application number EP20170199831). Dr. Cortegiani,

Dr. Accurso, and Dr. Gregoretto declare a patent pending, in association with the University of Palermo – Italy (No. 102019000020532 – Italian Ministry of Economic Development) related to the content of this manuscript. Dr. Gregoretto received fees for lectures by Philips, and received payments by Philips for consultancies in the developing process of the EVO Ventilator and fees for lectures or consultancies from Resmed, Vivisol and Air Liquide not related to the present work. The remaining authors have no conflict of interest to disclose.

Sources of support

None.

Funding

None declared.

References

1. Zhu N, Zhang D, Wang W, Li X, Yang B, Song J, et al. A novel coronavirus from patients with pneumonia in China, 2019. *N Engl J Med.* 2020;382:727–33.
2. Froes F. And now for something completely different: from 2019-nCoV and COVID-19 to 2020-nMan. *Pulmonology.* 2020;26:114–5.
3. Wu C, Chen X, Cai Y, Xia J, Zhou X, Xu S, et al. Risk factors associated with acute respiratory distress syndrome and death in patients with coronavirus disease 2019 pneumonia in Wuhan, China. *JAMA Intern Med.* 2020. <http://dx.doi.org/10.1001/jamainternmed.2020.0994>.
4. Guan WJ, Ni ZY, Hu Y, Liang WH, Ou CQ, He JX, et al. Clinical characteristics of coronavirus disease 2019 in China. *N Engl J Med.* 2020;382:1708–20.
5. Grasselli G, Zangrillo A, Zanella A, Antonelli M, Cabrini L, Castelli A, et al. Baseline characteristics and outcomes of 1591 patients infected with SARS-CoV-2 admitted to ICUs of the Lombardy Region, Italy. *JAMA.* 2020. <http://dx.doi.org/10.1001/jama.2020.5394>.
6. Livingston E, Bucher K. Coronavirus disease 2019 (COVID-19) in Italy. *JAMA.* 2020.
7. World Health Organization. Coronavirus disease (COVID-2019) situation reports; 2020.
8. Shi Y, Wang Y, Shao C, Huang J, Gan J, Huang X, et al. COVID-19 infection: the perspectives on immune responses. *Cell Death Differ.* 2020;27:1451–4.
9. Huang C, Wang Y, Li X, Ren L, Zhao J, Hu Y, et al. Clinical features of patients infected with 2019 novel coronavirus in Wuhan, China. *Lancet.* 2020;395:497–506.
10. Yang X, Yu Y, Xu J, Shu H, Xia J, Liu H, et al. Clinical course and outcomes of critically ill patients with SARS-CoV-2 pneumonia in Wuhan, China: a single-centered, retrospective, observational study. *Lancet Respir Med.* 2020. [http://dx.doi.org/10.1016/S2213-2600\(20\)30079-5](http://dx.doi.org/10.1016/S2213-2600(20)30079-5).
11. Gattinoni L, Chiumello D, Caironi P, Busana M, Romitti F, Brazzi L, et al. COVID-19 pneumonia: different respiratory treatments for different phenotypes? *Intensive Care Med.* 2020. <http://dx.doi.org/10.1007/s00134-020-06033-2>.
12. Bhatraju PK, Ghassemieh BJ, Nichols M, Kim R, Jerome KR, Nalla AK, et al. Covid-19 in critically ill patients in the seattle region – case series. *N Engl J Med.* 2020. <http://dx.doi.org/10.1056/NEJMoa2004500>.
13. Gattinoni L, Coppola S, Cressoni M, Busana M, Chiumello D. Covid-19 does not lead to a "typical" acute respira-

- tory distress syndrome. *Am J Respir Crit Care Med.* 2020, <http://dx.doi.org/10.1164/rccm.202003-0817LE>.
14. Demoule A, Hill N, Navalesi P. Can we prevent intubation in patients with ARDS? *Intensive Care Med.* 2016;42:768–71.
 15. Cortegiani A, Madotto F, Gregoretti C, Bellani G, Laffey JG, Pham T, et al. Immunocompromised patients with acute respiratory distress syndrome: secondary analysis of the LUNG SAFE database. *Crit Care.* 2018;22:157.
 16. Brochard L, Slutsky A, Pesenti A. Mechanical ventilation to minimize progression of lung injury in acute respiratory failure. *Am J Respir Crit Care Med.* 2017;195:438–42.
 17. Grieco DL, Menga LS, Raggi V, Bongiovanni F, Anzellotti GM, Tanzarella ES, et al. Physiological comparison of high-flow nasal cannula and helmet noninvasive ventilation in acute hypoxemic respiratory failure. *Am J Respir Crit Care Med.* 2020;201:303–12.
 18. Carreaux G, Millan-Guilarte T, De Prost N, Razazi K, Abid S, Thille AW, et al. Failure of noninvasive ventilation for de novo acute hypoxemic respiratory failure: role of tidal volume. *Crit Care Med.* 2016;44:282–90.
 19. Lucchini A, Giani M, Isgro S, Rona R, Foti G. The “helmet bundle” in COVID-19 patients undergoing non invasive ventilation. *Intensive Crit Care Nurs.* 2020;1028:59.
 20. Cammarota G, Vaschetto R, Turucz E, Dellapiazza F, Colombo D, Blando C, et al. Influence of lung collapse distribution on the physiologic response to recruitment maneuvers during noninvasive continuous positive airway pressure. *Intensive Care Med.* 2011;37:1095–102.
 21. Lindner KH, Lotz P, Ahnefeld FW. Continuous positive airway pressure effect on functional residual capacity, vital capacity and its subdivisions. *Chest.* 1987;92:66–70.
 22. Garofalo E, Bruni A, Pelaia C, Liparota L, Lombardo N, Longhini F, et al. Recognizing, quantifying and managing patient-ventilator asynchrony in invasive and noninvasive ventilation. *Expert Rev Respir Med.* 2018;12:557–67.
 23. Cortegiani A, Ippolito M, Lujan M, Gregoretti C. Tidal volume and helmet: is the never ending story coming to an end? *Pulmonology.* 2020, <http://dx.doi.org/10.1016/j.pulmoe.2020.02.001>.
 24. Bruni A, Garofalo E, Pelaia C, Messina A, Cammarota G, Mura-bito P, et al. Patient-ventilator asynchrony in adult critically ill patients. *Minerva Anestesiol.* 2019;85:676–88.
 25. Piehl MA, Brown RS. Use of extreme position changes in acute respiratory failure. *Crit Care Med.* 1976;4:13–4.
 26. Pelosi P, D’Andrea L, Vitale G, Pesenti A, Gattinoni L. Vertical gradient of regional lung inflation in adult respiratory distress syndrome. *Am J Respir Crit Care Med.* 1994;149:8–13.
 27. Gattinoni L, Caironi P, Cressoni M, Chiumello D, Ranieri VM, Quintel M, et al. Lung recruitment in patients with the acute respiratory distress syndrome. *N Engl J Med.* 2006;354:1775–86.
 28. Pelosi P, Tubiolo D, Mascheroni D, Vicardi P, Crotti S, Valenza F, et al. Effects of the prone position on respiratory mechanics and gas exchange during acute lung injury. *Am J Respir Crit Care Med.* 1998;157:387–93.
 29. Guerin C, Reignier J, Richard JC, Beuret P, Gacouin A, Boulain T, et al. Prone positioning in severe acute respiratory distress syndrome. *N Engl J Med.* 2013;368:2159–68.
 30. Gattinoni L, Tognoni G, Pesenti A, Taccone P, Mascheroni D, Labarta V, et al. Effect of prone positioning on the survival of patients with acute respiratory failure. *N Engl J Med.* 2001;345:568–73.
 31. Guerin C, Gaillard S, Lemasson S, Ayzac L, Girard R, Beuret P, et al. Effects of systematic prone positioning in hypoxemic acute respiratory failure: a randomized controlled trial. *JAMA.* 2004;292:2379–87.
 32. Taccone P, Pesenti A, Latini R, Polli F, Vagginelli F, Mietto C, et al. Prone positioning in patients with moderate and severe acute respiratory distress syndrome: a randomized controlled trial. *JAMA.* 2009;302:1977–84.
 33. Mure M, Nyren S, Jacobsson H, Larsson SA, Lindahl SG. High continuous positive airway pressure level induces ventilation/perfusion mismatch in the prone position. *Crit Care Med.* 2001;29:959–64.
 34. Gattinoni L, Taccone P, Carlesso E, Marini JJ. Prone position in acute respiratory distress syndrome. Rationale, indications, and limits. *Am J Respir Crit Care Med.* 2013;188:1286–93.
 35. Ding L, Wang L, Ma W, He H. Efficacy and safety of early prone positioning combined with HFNC or NIV in moderate to severe ARDS: a multi-center prospective cohort study. *Crit Care.* 2020;24:28.
 36. Cosentini R, Brambilla AM, Aliberti S, Bignamini A, Nava S, Maffei A, et al. Helmet continuous positive airway pressure vs oxygen therapy to improve oxygenation in community-acquired pneumonia: a randomized, controlled trial. *Chest.* 2010;138:114–20.
 37. Delclaux C, L’Her E, Alberti C, Mancebo J, Abroug F, Conti G, et al. Treatment of acute hypoxemic nonhypercapnic respiratory insufficiency with continuous positive airway pressure delivered by a face mask: a randomized controlled trial. *JAMA.* 2000;284:2352–60.
 38. Elliott MW. The interface: crucial for successful noninvasive ventilation. *Eur Respir J.* 2004;23:7–8.
 39. Antonelli M, Conti G, Pelosi P, Gregoretti C, Pennisi MA, Costa R, et al. New treatment of acute hypoxemic respiratory failure: noninvasive pressure support ventilation delivered by helmet – a pilot controlled trial. *Crit Care Med.* 2002;30:602–8.
 40. Cammarota G, Olivieri C, Costa R, Vaschetto R, Colombo D, Turucz E, et al. Noninvasive ventilation through a helmet in postextubation hypoxemic patients: physiologic comparison between neurally adjusted ventilatory assist and pressure support ventilation. *Intensive Care Med.* 2011;37:1943–50.
 41. Hui DS, Chow BK, Lo T, Ng SS, Ko FW, Gin T, et al. Exhaled air dispersion during noninvasive ventilation via helmets and a total facemask. *Chest.* 2015;147:1336–43.
 42. Cabrini L, Landoni G, Zangrillo A. Minimise nosocomial spread of 2019-nCoV when treating acute respiratory failure. *Lancet.* 2020;395:685.
 43. Rochweg B, Brochard L, Elliott MW, Hess D, Hill NS, Nava S, et al. Official ERS/ATS clinical practice guidelines: noninvasive ventilation for acute respiratory failure. *Eur Respir J.* 2017;50.
 44. Alhazzani W, Møller MH, Arabi YM, Loeb M, Gong MN, Fan E, et al. Surviving Sepsis Campaign: Guidelines on the Management of Critically Ill Adults with Coronavirus Disease 2019 (COVID-19). *Intensive Care Med.* 2020, <http://dx.doi.org/10.1007/s00134-020-06022-5>.
 45. Longhini F, Abdalla K, Navalesi P. Non-invasive ventilation in hypoxemic patients: does the interface make a difference? *Ann Transl Med.* 2016;4:359.
 46. Longhini F, Liu L, Pan C, Xie J, Cammarota G, Bruni A, et al. Neurally-adjusted ventilatory assist for noninvasive ventilation via a helmet in subjects with copd exacerbation: a physiologic study. *Respir Care.* 2019;64:582–9.
 47. Vaschetto R, Longhini F, Persona P, Ori C, Stefani G, Liu S, et al. Early extubation followed by immediate noninvasive ventilation vs. standard extubation in hypoxemic patients: a randomized clinical trial. *Intensive Care Med.* 2019;45:62–71.
 48. Cammarota G, Longhini F, Perucca R, Ronco C, Colombo D, Messina A, et al. New setting of neurally adjusted ventilatory assist during noninvasive ventilation through a helmet. *Anesthesiology.* 2016;125:1181–9.
 49. Mauri T, Spinelli E, Mariani M, Guzzardella A, Del Prete C, Carlesso E, et al. Nasal high flow delivered within the helmet: a new noninvasive respiratory support. *Am J Respir Crit Care Med.* 2019;199:115–7.

50. Garofalo E, Bruni A, Pelaia C, Cammarota G, Murabito P, Biamonte E, et al. Evaluation of a new interface combining high-flow nasal cannula and CPAP. *Respir Care*. 2019;64:1231–9.
51. Greenland JR, Michelow MD, Wang L, London MJ. COVID-19 infection: implications for perioperative and critical care physicians. *Anesthesiology*. 2020, <http://dx.doi.org/10.1097/ALN.0000000000003303>.
52. Borg GA. Psychophysical bases of perceived exertion. *Med Sci Sports Exerc*. 1982;14:377–81.
53. Olivieri C, Longhini F, Cena T, Cammarota G, Vaschetto R, Messina A, et al. New versus conventional helmet for delivering noninvasive ventilation: a physiologic, crossover randomized study in critically ill patients. *Anesthesiology*. 2016;124:101–8.
54. Cortegiani A, Navalesi P, Accurso G, Sabella I, Misseri G, Ippolito M, et al. Tidal volume estimation during helmet noninvasive ventilation: an experimental feasibility study. *Sci Rep*. 2019;9:17324.
55. Nyren S, Mure M, Jacobsson H, Larsson SA, Lindahl SG. Pulmonary perfusion is more uniform in the prone than in the supine position: scintigraphy in healthy humans. *J Appl Physiol* (1985). 1999;86:1135–41.
56. Benumof JL. Respiratory physiology and respiratory function during anesthesia. In: *Anesthesia*. Philadelphia: WB Saunders; 1994. p. 577–620.