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Paradoxically Improved Respiratory Compliance With Abdominal Compression in COVID-19 ARDS

To the Editor:

Respiratory system mechanics are influenced by the elastic properties of both elements of the series-coupled lung and chest wall.[1] Intraabdominal pressure (IAP) is a major contributor to chest wall elastance (and to its inverse, compliance).[1,2] Consequently, an increase in IAP typically results in an increase in plateau airway pressure (Pplat) and a parallel decrease in respiratory system compliance (Crs), calculated as tidal volume divided by driving pressure.[1,2] Recently, we have encountered multiple patients with severe ARDS caused by advanced COVID-19 (C-ARDS) who exhibited paradoxical and reproducible responses to increasing IAP, characterized by decreases in Pplat and increases in calculated Crs. In this report, we describe our experience with this phenomenon, suggest a possible explanation, and discuss its potential clinical relevance to ventilator adjustment.

The index case (Table 1, patient 1) was a 58-year-old morbidly obese woman with severe C-ARDS. Thirty days after intubation, despite being ventilated with a tidal volume of 5.5 mL/kg/ideal body weight and 8 cm H_2O positive end-expiratory pressure (PEEP), her Pplat was markedly elevated at 49 cm H_2O. In an attempt to decrease Pplat, she was placed in reverse Trendelenburg position.[3] Unexpectedly, this maneuver further increased Pplat; with resumption of the routine supine position, Pplat returned to the previous (lower) value. The bedside physician then noted that sustained manual compression of the abdomen, a maneuver that normally would be expected to decrease Crs by increasing IAP,[4-6] led to a paradoxical reduction in Pplat. The fall in Pplat was observed immediately after applying abdominal pressure and returned to the previous value as soon as abdominal pressure was released.

Because the data reported in this clinical case series was used to help guide ventilator adjustments, it did not meet the standard for informed consent or review by our institutional review board. Subsequently, we identified six patients, each deeply sedated and pharmacologically paralyzed, who demonstrated the same paradoxical reduction in Pplat during abdominal compression, performed manually by applying firm, continuous pressure to the upper abdomen for five to six respiratory cycles. Pplat was then measured on the fifth or sixth cycle. Baseline respiratory mechanics of these seven patients (three men and four women; age range, 50-75 years) are shown in Table 1. With one exception, patients were assessed $\geq$ 10 days after intubation (range, 4-40 days), and uniformly had very low Crs (range, 7.3-21.0 mL/cm H_2O). In each case, abdominal compression significantly decreased Pplat and increased Crs (Fig 1). These reductions of Pplat persisted over several tidal cycles until compression was stopped and rebounded to the original Pplat and Crs values within two tidal cycles of IAP release. Repeated abdominal compressions elicited identical effects. No end-expiratory gas trapping was evident in any case.

The effect of lowering PEEP on Pplat and Crs (without abdominal compression) was assessed in three of these seven patients. In each instance, reducing PEEP led to a disproportionate decrease in Pplat and increase in calculated Crs (Table 1; patients 4, 5, and 7). In two of these cases, manual compression at the lower level of PEEP no longer altered Pplat, but in the third case it reduced Plat even at the lower PEEP.

Discussion

COVID-19 has challenged our understanding of certain aspects of ARDS and in the process has broadened perspectives regarding the underlying physiology that guides ventilation. Despite severely impaired oxygenation, the gas volume and compliance of patients with C-ARDS may be initially well preserved.[7] However, in late phase C-ARDS, there may be impressive loss of aeratable lung units, fibroblastic proliferation, and organization.[8,9] In the current study, we document what we think to be an undescribed phenomenon in severe, late phase C-ARDS: reproducible improvement in Crs in response to manual compression of the upper abdomen. Without more detailed information, the reason for this paradoxical response must remain speculative. We think the most likely explanation is that abdominal compression leads to a reduction in end-expiratory lung

TABLE 1] Baseline Respiratory System Mechanics

Patient No.	Duration of Symptoms Prior to Observation (d)	Duration of MV Prior to Observation (d)	Tidal Volume (mL/kg/IBW)	PEEP (cm H_2O)	Pplat (cm H_2O)	Driving Pressure	Crs (mL/cm H_2O)
1	36	30	5.5	8	49	41	7.3
2	47	40	7.8	5	37	32	15.6
3	31	10	4.8	10	33	23	15.2
4	17	4	6.4	10	30	20	21.0
				5	15	10	42.0
5	23	15	4.6	8	38	30	10.6
				3	26	23	13.8
6	19	15	6.8	8	36	28	14.5
7	20	12	6.1	8	43	35	11.4
				5	32	27	14.8

Crs = respiratory system compliance; IBW = ideal body weight; MV = mechanical ventilation; PEEP = positive end-expiratory pressure; Pplat = plateau pressure.

volume that allows lung units that otherwise overdistend at end-inflation to operate on a more linear portion of their pressure-volume curves.[10] Manual abdominal compression increases intrapleural pressure,[6] an effect that would normally cause a commensurate rise in Pplat. However, if the upper inflection zone of the sigmoidal pressure-volume curve were breached during tidal ventilation, this may be more than offset by a reduction in lung volume during the maneuver that improves tidal compliance. In support of this hypothesis, we found in three of the patients that a relatively small decrease in PEEP produced a much larger reduction in Pplat, clearly indicating that the end-inspiratory volumes of the inflatable lung units were positioned well above their upper inflection points during tidal ventilation, even at moderate PEEP. Furthermore, during application of a square inspiratory waveform, the concavity of the airway pressure tracing straightened noticeably during the belly push (Fig 2).

A characteristic feature of late phase, unresolving ARDS of any cause, including COVID-19, is markedly reduced

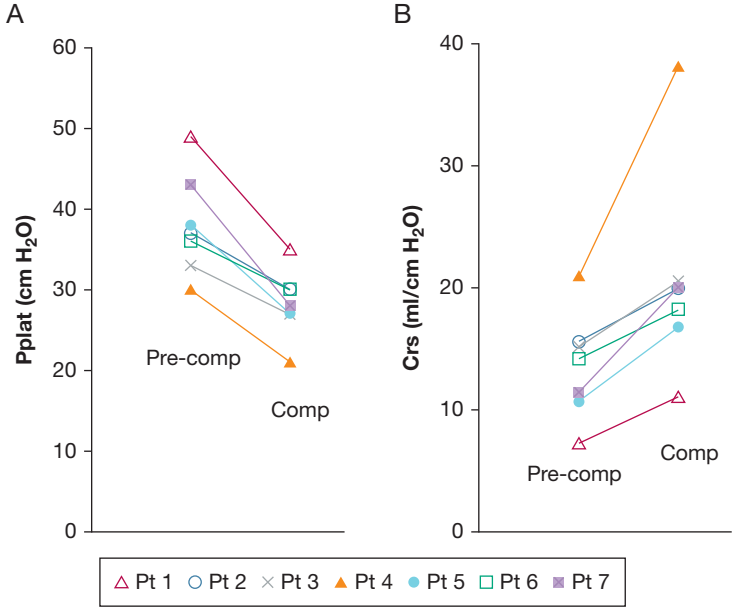

Figure 1 – *A-B, Effect of abdominal compression on respiratory mechanics. Pplat and Crs at Comp and Pre-comp at initial positive end-expiratory pressure settings. Comp = during compression; Crs = respiratory system compliance; Pplat = plateau pressure; Pre-comp = before compression; Pt = patient.*

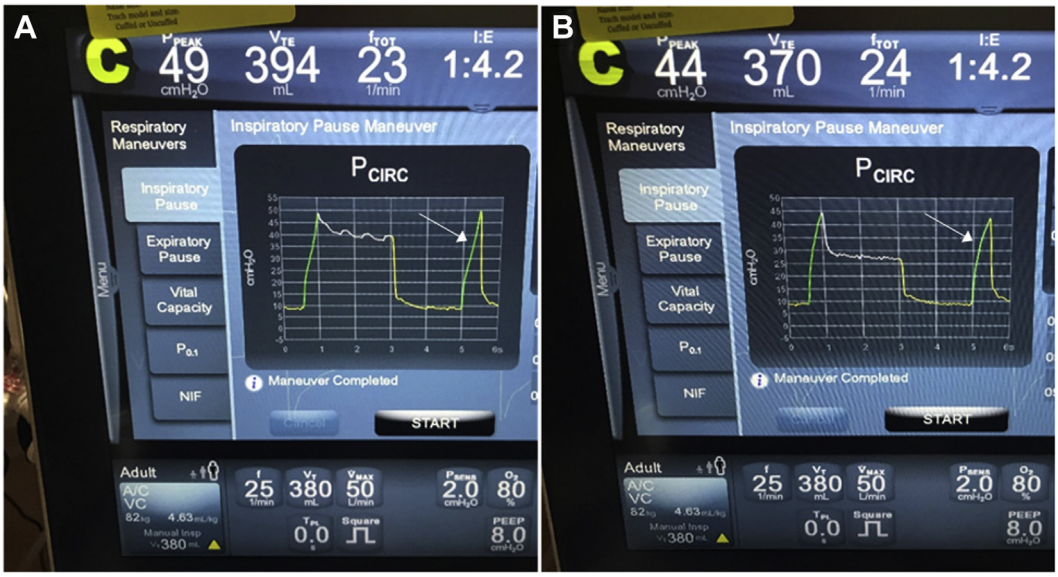

Figure 2 – *A-B, Airway pressure tracings of patient 5. A, Before compression. B, During compression. Upper concavity of the pressure-time tracing during compression suggesting overdistension is no longer present during compression (arrows).*

Crs, with high physiological dead space, and relatively few alveolar units recruitable by increasing PEEP. Very low Crs characterized each of the seven patients (Table 1). In such cases, ventilation with an often recommended tidal volume of 6 mL/kg/ideal body weight and moderate levels of PEEP (8-10 cm H_2O) may overdistend aeratable lung without dynamic hyperinflation, causing end-inspiratory lung volume to rise above the upper inflection point of the pressure-volume curve. We suggest that a paradoxical decrease in Pplat in response to abdominal compression may be a sign of end-inspiratory overdistention that should prompt consideration of lowering of PEEP, tidal volume, or both.

This preliminary report of patients who are critically ill is intended to quickly call to attention an undescribed and clinically relevant phenomenon for today's pandemic practice. As such, it is limited by the absence of dynamic imaging and measurement of abdominal and pleural pressures. Although described here in late phase C-ARDS from a single center, from verbal communications with our colleagues, this phenomenon appears to be relatively common elsewhere; we do not know its true incidence. However, the simple and immediately reversible maneuver we describe is universally applicable even in poorly resourced environments, may have implications for managing patients afflicted by COVID-19, and opens several avenues for mechanism-defining research investigation. Based on the observations reported in this current pilot study, we propose that the Pplat response to manual compression of the abdomen in the supine position may provide a useful indicator of the safety margin to avoid tidal lung overdistention.

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