Complete Airway Closure

Where, Why, and with What Consequences?

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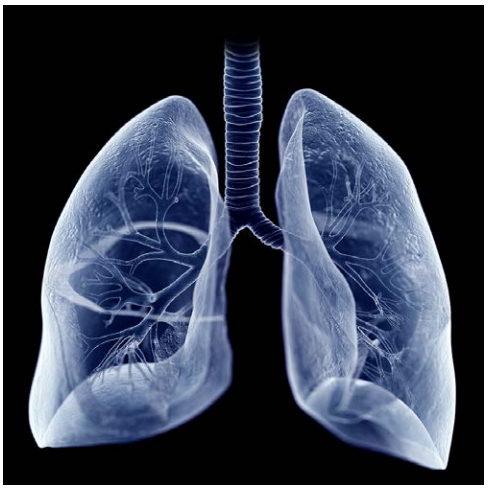
PULMONARY atelectasis in the anesthetized and mechanically ventilated patient was first suggested 1963[1] and demonstrated using computed tomography in the 1980s.[2] Many studies have since then been performed, both during anesthesia in essentially lung-healthy subjects[3] and in mechanically ventilated patients with acute respiratory failure.[4] In 1967 another morphological phenomenon was proposed in both healthy and sick lungs—that is, airway closure.[5] It was initially demonstrated by indirect means using gas dilution techniques. Recently, airway closure could also be more directly visualized in anesthetized rabbits using a synchrotron radiation technique, seen mainly in the 18th generation of airways.[6] This "classic" airway closure occurs when pressure outside the airway is higher than inside. The outside pressure equals, more or less, the pleural pressure and increases down the lung, primarily related to the weight of the lung. Airways in dependent lung regions are therefore exposed to a higher pressure than elsewhere and are the first to close during expiration. If airways are continuously closed or open only briefly, as in elderly and obese patients, resorption of alveolar gas into the capillary blood will cause atelectasis, and this is the major, almost only cause of atelectasis during anesthesia.[7] This cyclic opening and closing of airways may trigger an inflammatory response that may be as important, or more, as atelectasis.[8]



"...data...illustrate a new observation of respiratory dysfunction, complete airway closure...[that] differs from the classic airway closure phenomenon that can be seen in peripheral airways..."

In the study by Coudroy *et al.*[9] in this issue ANESTHESIOLOGY, airway closure was shown to be common in obese, mechanically ventilated patients with varying degree of acute respiratory distress syndrome. This may not come as a surprise, but what was unexpected was *complete* airway closure that has also been demonstrated in obese patients during anesthesia.[10] This implies that when starting inspiration, no gas can enter the lung until a certain airway opening pressure is reached. The authors concluded that the phenomenon is not an intrinsic positive end-expiratory pressure, or auto-PEEP, as is seen when expiration is interrupted by the next inspiration. Therefore, where is this closure located and what consequences may follow?

Coudroy *et al.*[9] suggest the complete airway closure to be located in small peripheral airways because these critically ill patients had signs of small airway damage. However, there are up to 23 generations of airways divided by dichotomy down to the alveoli, resulting in thousands of airways, and essentially all of them shall close and open at the same time to cause complete airway closure and opening. Moreover, the pressure outside the airway wall will differ depending on whether the airway is located in dependent or nondependent portions of the lung. Can it be that this complete airway closure is in the large airways, even in the trachea? The obese patient may have more tissue surrounding the trachea, and changes in body position can cause displacement of the extratracheal tissue such that it exerts pressure on the tracheal wall. Loss of tracheal muscle tone by anesthesia and sedation may facilitate complete obstruction of the trachea.[11] That this is the mechanism behind complete airway closure is conjecture, but it would be interesting to demonstrate any obstruction of the trachea or possibly main bronchi and to measure pressure some distance down the airway tree to see when pressure increases on an inspiration: early if there is peripheral closure, late if it is central

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in nature. An inspiratory respiratory compliance of 2 to 2.5 ml/cm H_2O before airway opening pressure is reached has been measured in studies on complete airway closure[8,12] and is suggested to reflect the compliance of the ventilator circuit itself. A higher compliance would be expected if the airway tree is included, as when complete closure is in the periphery.[13] However, it should be emphasized that central airway obstruction does not preclude simultaneous peripheral airway damage. Surfactant depletion may add to both central and peripheral airway instability and cause widespread closure and injury, also in distal airways.[14,15]

The other aspect carefully discussed by Coudroy *et al.*[9] is the need to consider airway opening pressure when calculating respiratory mechanics. Interestingly, there was an association between complete airway closure and auto-PEEP, and no patient without auto-PEEP had complete airway closure. Perhaps there is a link between these two phenomena. Expiratory flow decreases when alveolar recoil pressure decreases and airways get narrower with decreasing lung volume. At some point along the airway tree, the outside and inside airway pressure may become equal (so called equal pressure point[16]), and from here on toward airway opening the airway may be obstructed. This further decreases expiratory flow (possibly resulting in an auto-PEEP effect) and, if obstruction is complete, expiration stops (complete airway closure). Moreover, with the next inspiration, airway pressure has to exceed the auto-PEEP and, if complete obstruction occurred, the airway opening pressure. Whether deliberate expiratory flow limitation by an external device can be a tool to balance complete airway closure would appear to be of interest to evaluate in future studies.

Finally, the authors discuss chest wall elastance and did not see any increase in the obese patients. This may appear surprising, but it should be emphasized that increased weight of the chest wall (*e.g.*, increased amount of fat) will require more pressure only when the tissue is displaced during an inspiration. When inspiration is completed, no pressure is needed for displacement, only to keep the chest wall expanded, and this pressure may not be any larger than normal with an obese chest wall. What is surprising is that the authors found a positive association between body mass index and end-expiratory esophageal pressure. This can hardly be related to an increased chest wall elastance but may rather reflect chest wall weight. Otherwise the question remains, what causes an increased esophageal pressure at end-expiration with increasing body mass index?

To summarize, the authors have put together data that illustrate a new observation of respiratory dysfunction, *complete airway closure*. It differs from the classic airway closure phenomenon that can be seen in peripheral airways, whereas complete closure may have a more central location in the airway tree. Can this observation have implications for treatment to prevent the phenomenon of complete airway closure? Potential interventions might include alteration of body positioning, (cautious) use of muscle relaxants, deliberate expiratory flow limitation, or to set external PEEP as high or higher than airway opening pressure. Hopefully more studies are in store to test this hypothesis.

Competing Interests

The author is not supported by, nor maintains any financial interest in, any commercial activity that may be associated with the topic of this article.

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References

1. Bendixen HH, Hedley-Whyte J, Laver MB: Impaired oxygenation in surgical patients during general anesthesia with controlled ventilation; A concept of atelectasis. N Engl J Med 1963; 269:991–6
2. Brismar B, Hedenstierna G, Lundquist H, Strandberg A, Svensson L, Tokics L: Pulmonary densities during anesthesia with muscular relaxation: A proposal of atelectasis. Anesthesiology 1985; 62:422–8
3. Duggan M, Kavanagh BP: Pulmonary atelectasis: A pathogenic perioperative entity. Anesthesiology 2005; 102:838–54
4. Gattinoni L, Caironi P, Cressoni M, Chiumello D, Ranieri VM, Quintel M, Russo S, Patroniti N, Cornejo R, Bugedo G: Lung recruitment in patients with the acute respiratory distress syndrome. N Engl J Med 2006; 354:1775–86
5. Dollfuss RE, Milic-Emili J, Bates DV: Regional ventilation of the lung studied with boluses of 133 Xenon. Respir Physiol 1967; 2:234–46
6. Broche L, Pisa P, Porra L, Degrugilliers L, Bravin A, Pellegrini M, Borges JB, Perchiazzi G, Larsson A, Hedenstierna G, Bayat S: Individual airway closure characterized *in vivo* by phase-contrast CT imaging in injured rabbit lung. Crit Care Med 2019; 47:e774–81
7. Hedenstierna G, Tokics L, Scaramuzzo G, Rothen HU, Edmark L, Öhrvik J: Oxygenation impairment during anesthesia: Influence of age and body weight. Anesthesiology 2019; 131:46–57
8. Chen L, Del Sorbo L, Grieco DL, Shklar O, Junhasavasdikul D, Telias I, Fan E, Brochard L: Airway closure in acute respiratory distress syndrome: An underestimated and misinterpreted phenomenon. Am J Respir Crit Care Med 2018; 197:132–6
9. Coudroy R, Vimpere D, Aissaoui N, Younan R, Bailleul C, Couteau-Chardon A, Lancelot A, Guerot E, Chen L, Brochard L, Diehl J-L: Prevalence of complete airway closure according to body mass index in acute

respiratory distress syndrome: Pooled cohort analysis. Anesthesiology 2020; 133:867–78
10. Grieco DL, Anzellotti GM, Russo A, Bongiovanni F, Costantini B, D'Indinosante M, Varone F, Cavallaro F, Tortorella L, Polidori L, Romanò B, Gallotta V, Dell'Anna AM, Sollazzi L, Scambia G, Conti G, Antonelli M: Airway closure during surgical pneumoperitoneum in obese patients. Anesthesiology 2019; 131:58–73
11. Richardson J, Béland J: Nonadrenergic inhibitory nervous system in human airways. J Appl Physiol 1976; 41(5 Pt. 1):764–71
12. Sun XM, Chen GQ, Zhou YM, Yang YL, Zhou JX: Airway closure could be confirmed by electrical impedance tomography. Am J Respir Crit Care Med 2018; 197:138–41
13. Hedenstierna G, Lundberg S: Airway compliance during artificial ventilation. Br J Anaesth 1975; 47:1277–81
14. Broche L, Perchiazzi G, Porra L, Tannoia A, Pellegrini M, Derosa S, Sindaco A, Batista Borges J, Degrugilliers L, Larsson A, Hedenstierna G, Wexler AS, Bravin A, Verbanck S, Smith BJ, Bates JH, Bayat S: Dynamic mechanical interactions between neighboring airspaces determine cyclic opening and closure in injured lung. Crit Care Med 2017; 45:687–94
15. Coudroy R, Lu C, Chen L, Demoule A, Brochard L: Mechanism of airway closure in acute respiratory distress syndrome: A possible role of surfactant depletion. Intensive Care Med 2019; 45:290–1
16. Mead J, Turner JM, Macklem PT, Little JB: Significance of the relationship between lung recoil and maximum expiratory flow. J Appl Physiol 1967; 22:95–108