Extraluminal tissue pressure: what does it mean?

In this issue of the *Journal of Applied Physiology*, Kairaitis et al. (9) examine the control of pharyngeal extraluminal tissue pressure by mandibular advancement and jaw position. Utilizing a novel approach for measuring peripharyngeal tissue pressures, they demonstrated that mandibular advancement decreased tissue pressures anterior and lateral to the airway lumen. Decreases in the lateral peripharyngeal tissue pressure led to the greatest improvement in airway patency when the mouth was closed. These investigators concluded that regional tissue pressures were differentially regulated based on the direction of mandibular advancement. Observed differences in force transmission to the lateral and anterior peripharyngeal space have both mechanistic and clinical implications.

Extraluminal tissue pressure has long been considered an important determinant of upper airway patency (4, 5, 16-18, 24). It influences the degree of airway collapse by changing the transmural pressure, which is defined as the difference between the intraluminal and extraluminal pressures. Initial efforts to model the upper airway as a simple collapsible conduit highlighted the impact of transmural pressure changes on airway patency (5, 16–18). The upper airway remained patent when the transmural pressure was positive, and it was occluded when the transmural pressure became negative. In early studies, the extraluminal tissue pressure was inferred by determining the nasal pressure required to occlude the upper airway. In sleep apnea patients, the airway occluded at positive nasal pressures, implying a positive extraluminal tissue pressure during sleep (18). In contrast, normal individuals required a subatmospheric nasal pressure to occlude the upper airway, implying that the extraluminal tissue pressure was negative (17). In fact, as subatmospheric pressure was applied and the transmural pressure became negative, the upper airway occluded (17), and recurrent obstructive apneas, oxyhemoglobin desaturations, and arousals from sleep ensued (10). Thus the transmural pressure was considered the essential physiological determinant of upper airway patency, with decreases in transmural pressure (below atmosphere) causing obstructive sleep apnea.

In addition to alterations in transmural pressure, investigators subsequently found that mucosal tension within the airway wall can also influence upper airway patency (13). When caudal traction was applied to the trachea, an increase in tension within the pharyngeal mucosa substantially decreased upper airway collapsibility (13, 20–22). Decreased collapsibility was attributed to stiffening of the pharyngeal wall rather than reductions in extraluminal tissue pressures, as previously described (5). Moreover, caudal traction amplified the decrease in upper airway collapsibility when pharyngeal structures were dilated simultaneously (14). Thus forces acting simultaneously in longitudinal and radial directions interacted to stabilize pharyngeal patency. The conceptual basis for this interaction is depicted in Fig. 1, which illustrates how stiffening the airway mucosa can enhance the effect of dilating forces on extraluminal pressure. As shown, forces acting in parallel or perpendicular to the airway lumen can reduce collapsibility through distinct effects on airway wall tension and extraluminal tissue pressure.

In the present issue, Kairaitis et al. (9) provide direct evidence in rabbits that mandibular advancement, which dilates the pharyngeal lumen, decreases upper airway collapsibility by lowering extraluminal tissue pressures. In addition, they further established a directional component in the regulation of extraluminal tissue pressures by mandibular advancement. Their findings support the concept that greater decreases in surrounding tissue pressures occur when forces are applied in both the longitudinal (axial) and radial directions (Fig. 1). Thus mandibular advancement may be most effective in restoring pharyngeal patency when it exerts directional forces that both decompress surrounding tissues and stiffen the pharyngeal wall.

Kairaitis et al. (9) provide additional insight into underlying mechanisms of upper airway obstruction in humans during anesthesia and sleep. Isono and coworkers (8, 23) have suggested that the mandible forms a boney enclosure around the pharynx. They have shown that upper airway collapsibility, as reflected by measurements of critical closing pressures, varies inversely with mandibular size and position, and they have suggested that compression of extraluminal tissues by the mandible can account for elevations in collapsibility. Mouth opening, which reduces the size of the bony enclosure, has been associated with substantial increases in upper airway collapsibility (critical closing pressures) (1, 7, 19). Kairaitis et al. (9) have extended this model, and they provide direct evidence for reductions in extraluminal tissues with mandibular advancement. Decreases in the lateral peripharyngeal tissue pressure led to the greatest improvement in airway patency (resistance) when the mouth was closed, consistent with the notion that collapse of the lateral pharyngeal walls plays a major role in the pathogenesis of upper airway obstruction during sleep (11, 15). These findings also suggest that the susceptibility to airway obstruction may be primarily related to a loss of mucosal tension and that therapeutic responses to mandibular advancement (12) may be enhanced by minimizing mouth opening and increasing longitudinal wall tension simultaneously. Indeed, airway narrowing in the lateral dimension may be viewed as a sensitive marker for underlying defects in longitudinal tension that predispose to obstructive sleep apnea (15).

The work by Kairaitis et al. (9) still leaves several questions unanswered. First, although the present methods can be used to approximate the relative changes in extraluminal tissue pressures with mandibular manipulation, they may well underestimate the impact of tissue pressure on critical transmural pressures associated with airway collapse (2, 3). Second, the investigators report the effect of mandibular advancement on upper airway resistance rather than collapsibility (critical closing pressure). Critical closing pressure measurements could be used to partition effects of mandibular advancement between the extraluminal tissues and airway wall. Third, the effects of upper airway neuromuscular activity on extraluminal tissue pressure remain to be elucidated. Nevertheless, Kairaitis et al. have advanced our understanding of extraluminal tissue pressure and its potential contribution to the pathogenesis of obstructive sleep apnea.
Fig. 1. Effects of caudal and radial traction on mucosal tension and extraluminal tissue pressure. Caudal traction leads to an increase in mucosal tension (see C and D), whereas radial traction decompresses the surrounding tissues (see A and B). The effect of radial traction on surrounding tissue pressure is enhanced when the mucosa is taut (compare C and D vs. A and B). [Modified from Rowley JA et al. (13).]

REFERENCES


Alan R. Schwartz
Jason Kirkness
Philip Smith
Johns Hopkins Sleep Disorders Center
Division of Pulmonary and Critical Care Medicine
Johns Hopkins University School of Medicine
Baltimore, Maryland
e-mail: aschwar2@jhmi.edu