Effects of pulmonary vascular pressures and flow on airway and parenchymal mechanics in isolated rat lungs

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Peták, Ferenc, Walid Habre, Zoltán Hantos, Peter D. Sly, and Denis R. Morel. Effects of pulmonary vascular pressures and flow on airway and parenchymal mechanics in isolated rat lungs. J Appl Physiol 92: 169–178, 2002.—Changes in pulmonary hemodynamics have been shown to alter the mechanical properties of the lungs, but the exact mechanisms are not clear. We therefore investigated the effects of alterations in pulmonary vascular pressure and flow (Qp) on the mechanical properties of the airways and the parenchyma by varying these parameters independently in three groups of isolated perfused normal rat lungs. The pulmonary capillary pressure (Pc,est), estimated from the pulmonary arterial (Ppa) and left atrial pressure (Pla), was increased at constant Qp (n = 7), or Qp was changed at Pc,est = 10 mmHg (n = 7) and at Pc,est = 20 mmHg (n = 6). In each condition, the airway resistance (Raw) and parenchymal damping (G) and elastance (H) were identified from the low-frequency pulmonary input impedance spectra. The results of measurements made under isogravimetric conditions were analyzed. The changes observed in the mechanical parameters were consistent with an altered Pla: monotonous increases in Raw were observed with increasing Pla, whereas G and H were minimal at Pla of 7–10 mmHg and increased at lower and higher Pla. The results indicate that Pla, and not Ppa or Qp, is the primary determinant of the mechanical condition of the lungs after acute changes in pulmonary hemodynamics: the parenchymal mechanics are impaired if Pla is lower or higher than physiological, whereas airway narrowing occurs at high Pla.

respiratory mechanics; forced oscillations; pulmonary circulation

PREVIOUS STUDIES HAVE DEMONSTRATED that changes in pulmonary hemodynamic conditions alter the mechanical properties of the lungs (1–3, 5–7, 9–11, 13, 15, 19–24, 26–28). A compromised lung function has been observed in clinical situations involving an abnormally high pulmonary blood flow (Qp) (9, 11, 13, 22, 24) and/or an elevated pulmonary arterial pressure (Ppa) (1–3, 5, 6, 20, 23, 26–28). Nevertheless, the results of these previous studies lead to inconsistent conclusions as to which of the pulmonary hemodynamic parameters has the dominant effect on lung mechanics.

The elevated Qp has been reported to be the primary cause of the decreased lung compliance (C L) in adults with cardiac failure (11) and in children with congenital heart disease (13, 22, 24), although normal Cl values have also been found in children with a high Qp and a normal Ppa (2, 15). Conversely, a high Ppa has been demonstrated to play a major role in determining the mechanical properties of the lungs, since changes were observed only when Ppa was elevated (2, 15, 27, 28). Finally, other authors observed abnormal lung function only when an increased Qp was associated with an elevated Ppa (3, 20).

Many factors may contribute to these discrepancies, including the complex nature of heart diseases, different underlying clinical conditions, or timing and methodological differences between the studies. Additionally, the clinical settings do not allow separate alterations of Ppa or Qp, and accordingly the primary cause of the compromised lung function cannot be identified. Finally, these previous studies used global parameters to characterize the mechanical status of the lungs, and their results therefore combined the contributions from the airways and the respiratory tissues.

In clinical practice, it is possible to influence the pulmonary hemodynamic parameters relatively selectively by pharmacological means; hence, it is important to clarify the mechanism responsible for the adverse changes in lung mechanics. We therefore set out to investigate the effects of acutely altered left atrial pressure (Pla), Ppa, and Qp on the mechanical properties of the airways and the parenchyma before the onset of edema by varying these parameters independently.

METHODS

Animal preparation and isolated lung harvesting. Experiments were performed on 20 adult male Sprague-Dawley

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rats weighing 360–390 g. The rats were anesthetized with isoflurane via a facemask (3% induction, 1.4% maintenance dose); tracheotomized with a polyethylene cannula (14-gauge, Braun, Melsungen, Germany), and mechanically ventilated (model 683, Harvard Apparatus, South Natick, MA) with a tidal volume of 7 ml/kg and a respiratory rate of 70–80/min while a positive end-expiratory pressure of 2.5 cmH₂O was maintained. Respiratory gases were monitored in the expiratory circuit of the ventilator (Ultima, Datex/Instrumentarium, Helsinki, Finland). Airway opening pressure was measured continuously (DP 45 transducer and 2D15 carrier demodulator, Validyne, Northridge, CA).

The femoral vessels were cannulated with a 28-gauge catheter (Portex, Hythe, UK) for blood sampling and continuous arterial blood pressure monitoring with a pressure transducer (model 156 PCE 06-GW2, Honeywell, Zurich, Switzerland). The rats were fully anticoagulated with heparin (1.5 IU/g). Thirty-five ml of blood diluted in colloid solution were then gently withdrawn over 5 min via the arterial cannula, while the collected blood was continuously replaced by an intravenous infusion of colloid solution (6% hydroxyethyl starch solution). A constant intravascular volume and a mean systemic blood pressure >50 mmHg were maintained by this maneuver to minimize the risk of lung ischemic lesions. The collected diluted blood was centrifuged (4,000 rpm for 10 min), and 17 ml of plasma were extracted. The resulting concentrated blood with a hematocrit of ~35% served as priming perfusate.

A midline sternotomy was performed, and the chest was widely retracted. A polyethylene catheter (14-gauge, Braun) was placed into the main pulmonary artery via the right ventricular outflow track, advanced to immediately below its bifurcation, and connected to medical-grade silicone rubber tubing (1.47 mm ID, Ulrich, St. Gallen, Switzerland). The left ventricle and the left atrium were then widely opened, allowing free outflow of the remaining blood and resulting in complete exsanguination and the death of the animal.

The lungs were immediately flushed through the pulmonary artery cannula with 30 ml of cold (10°C) hydroxyethyl starch 6% solution from a height of 30 cm to minimize the warm ischemic time period until reperfusion. Another catheter was placed in the left ventricle through the left ventriculotomy, in which a Combitfix Adapter (Braun) was tightly fixed and connected to medical-grade silicone rubber tubing. Finally, a third catheter (polyethylene tubing, ID 0.88 mm, Portex) was introduced directly into the left atrium for the measurement of Pla. The surgical preparations were performed in a sterile manner. The lungs and the heart were extracted in a single block, dissected free of adjacent tissue, and weighed.

Perfusion of the isolated lungs. The experimental setup is shown schematically in Fig. 1. In a thermostabilized, humidified Plexiglas chamber, the heart-lung block was suspended from an isometric force displacement transducer (model FT03, Grass Instruments, Quincy, MA), which continuously measured weight changes. The lungs were ventilated with room air mixed with 5% CO₂ if this was indicated by the blood-gas analysis (model 683, Harvard Apparatus, South Natick, MA) with a tidal volume of 7 ml/kg and a respiratory rate of 70–80/min while a positive end-expiratory pressure of 2.5 cmH₂O were maintained.

The perfusion circuit was primed with the rat’s own blood after filtration (standard 200-µm filter) to remove possible debris. Lung perfusion was performed from a reservoir positioned initially to correspond to a pulmonary artery perfusion pressure (Ppa) of 15 mmHg and adjusted thereafter to different heights to produce various Ppa values (see below). The distal extremity of the left ventricle outflow cannula was placed at a sufficient height to obtain a Pla of 7.5 ± 2 mmHg at the beginning of the perfusion, which produces West zone 3 conditions (Ppa > Pla > alveolar pressure). The blood dripping from this cannula was collected in a 5-ml cylinder and aspirated from this reservoir with polyethylene tubing passing through a roller pump (Ismatec Pump, Glattburg, Zurich, Switzerland). A transit-time flowmeter (model T-201 CDS, Transonic Systems, Ithaca, NY) was placed between the perfusion reservoir and the catheter cannulating the main pulmonary artery for the continuous monitoring of Qp. The priming volume of the tubing and reservoirs was 18 ml.

The mean Ppa and Pla were recorded continuously with pressure transducers (model 156-PC 06-GW2, Honeywell) zeroed at the level of the lung hilus. Pulmonary vascular resistance (Rv) was calculated as follows: 

\[
R_v = \frac{(P_{pa} - P_{la})}{Q_p} 
\]

Pulmonary microvascular pressure (Pc_mic) was estimated by applying the Gaar equation (14):

\[
P_{c_{mic}} = P_{la} + 0.44 \times (P_{pa} - P_{la})
\]

Weight, Ppa, Pla, and Qp were sampled at a rate of 50 Hz by an analog-to-digital converter. These signals, together with the calculated Pc_mic, were displayed continuously by data acquisition software (Biopac, Santa Barbara, CA) and stored on a microcomputer (AST, Limerick, Ireland).

The temperature and pH of the perfusate were measured with a pH meter (model 691, Metrohm, Herisau, Switzerland). The pH was maintained between 7.35 and 7.45 and corrected with sodium bicarbonate or a change of the inspired CO₂ if this was indicated by the blood-gas analysis (model 505, Acid Base Laboratory, Copenhagen, Denmark). Steady-state gas exchange was confirmed by the stable PO₂, PCO₂, and hematocrit levels during the experiments.

Measurement of airway and parenchymal mechanics. The respective contributions of the airways and tissues to the total lung resistance were estimated by measuring the forced oscillatory impedance of the isolated lungs (ZL), as described previously (25). Briefly, the tracheal cannula was connected from the respirator to a loudspeaker-in-box system at end expiration. The loudspeaker generated a small-amplitude pseudorandom signal with frequency components between 0.5 and 21 Hz through a polyethylene wave tube with known geometry. Two identical pressure transducers (model 33NA002D, ICSensors, Milpitas, CA) were used for measurement of the lateral pressures at the loudspeaker and at the
tracheal end of the wave tube. Zt was calculated as the load impedance of the wave tube (29). To separate the airway and tissue mechanics, a model containing a frequency-independent airway resistance (Raw) and inertance (Iaw) in series with a constant-phase tissue compartment (18), including parenchymal damping (G) and elastance (H), was fitted to the Zt spectra by minimizing the relative differences between the measured and modeled impedance values (18). Tissue hysteresis was calculated as follows: \( \eta = G/H \) (12).

The load impedance of the endotracheal tube and the connecting tubing was also determined, and the Raw and Iaw values were corrected by subtracting the instrumental resistance and inertance values from them.

**Study protocol.** After the start of the perfusion, a period of 20–30 min was allowed for the respiratory and hemodynamic variables to establish steady-state conditions and for the preparation to become isogravimetric. If isogravimetric conditions were not reached within 30 min of perfusion or if Qp was \(<5\, \text{ml/min at normal Ppa and Pla values, the lungs were excluded (this occurred in \(<10\% of the experiments because of technical problems in the surgical preparation).}\)

The lungs were then randomly assigned to one or another of the following four protocol groups.

The lungs in the control group (n = 4) were used to estimate the stability of the perfused rat lung preparation. These lungs were perfused for 2 h while a Ppa of 17.5 mmHg and a Pla of 7.5 mmHg were maintained and the resulting Qp was constant. Four to six Zt recordings were made and ensemble averaged every 20 min.

In another group of lungs (n = 7), the perfusion of the lungs was established by applying normal levels of Ppa (17.5 mmHg) and Pla (7.5 mmHg). The resulting flow (5–6 ml/min) was then kept constant for each lung during the experiments, while the mean Pcest was altered from 5 to 25 mmHg in steps of 5 mmHg. This was accomplished by elevating the perfusion reservoir to increase Ppa and simultaneously adjusting Pla through elevation of the outflow level of the left ventricular cannula to a sufficient height.

In the next group of lungs (n = 7), Qp was doubled stepwise from 2.5 to 15 ml/min, while the mean Pcest was kept at an approximately physiological value of 10 mmHg to investigate the role of the altered Qp on the lung mechanics. In this group, elevation of the perfusion reservoir was associated with a lowering of the outflow level of the left ventricular cannula.

Finally, Qp was altered while Pcest was kept abnormally high. In these lungs (n = 6), a Pcest of 20 mmHg was set after the perfusion had reached the steady state, and Qp was decreased from 30 ml/min in 5 ml/min steps until a Qp of 5 ml/min was achieved, and it was then decreased to 2.5 ml/min. This was accomplished by decreasing and increasing the heights of the perfusion reservoir and the outflow of the left ventricular catheter, respectively. The changes in Qp made it necessary to alter the blood volume delivered by the roller pump into the perfusion reservoir.

A period of 5–10 min was necessary in all lungs to establish the steady-state conditions after a change in Pcest or Qp. Four to six Zt recordings were collected thereafter in each hemodynamic condition and were ensemble averaged. The weight gain was calculated during Zt measurements, i.e., when steady-state conditions had been established, and it was used as an edema index. There was no statistically significant difference in the size of the lungs in the various protocol groups.

**Statistical analysis.** Scatters in the parameters were expressed in SE values. We used one-way analysis of variances with the Student-Newman-Keuls multiple comparison procedure to compare the lung mechanical parameters under different hemodynamic conditions. Each test was performed with a significance level of \( P < 0.05 \).

**RESULTS**

None of the mechanical parameters in the control lungs exhibited a statistically significant change. After 2 h of perfusion, the relative changes in Raw, Iaw, G, and H were \( 1.0 \pm 5.2\%, -5.9 \pm 2.2\%, -3.9 \pm 2.6\%, \) and \( 3.3 \pm 2.2\% \), respectively. No signs of edema development were detected in these lungs, since the weight gain values were not statistically significantly different from zero (0.05 \pm 0.12 mg/min, \( P = 0.51 \) after 2 h of perfusion).

Figure 2 summarizes the results obtained at different levels of Pcest while Qp was kept constant. The accumulation of extravascular fluid did not contribute to the changes observed in the mechanical parameters until Pcest = 20 mmHg was reached; increases in weight gain were evident only at Pcest = 25 mmHg. Increasing Pcest caused gradual increases in Raw, which reached statistically significant levels at \( >15 \) mmHg. The highest relative change in Raw before edema development was 22.1 \pm 7.8\% (at 20 mmHg) compared with the value at the physiologically normal Pcest of 10 mmHg. No systematic change was observed in Raw in response to changes in Pcest. G and H responded to the altered Pcest with similar patterns of change: they were minimal at Pcest = 10 mmHg and exhibited statistically significant increases at lower (20.9 \pm 4.5\% for G and 17.1 \pm 4.2\% for H at 5 mmHg) and higher Pcest values (26.9 \pm 3.4 and 26.7 \pm 5.5\%, respectively, at 20 mmHg). The similar changes in G and H resulted in fairly constant \( \eta \) values. Rv was highest at Pcest = 5 mmHg; it decreased slightly at higher Pcest.

The changes recorded in the parameters when Qp was altered at Pcest = 10 mmHg are illustrated in Fig. 3. Edema did not develop in this group at any level of Qp. No statistically significant changes occurred in the airway parameters; the maximal relative changes in Raw and Pccest were 32.3 \pm 15.1 and \(-30.5 \pm 11.5\% \), respectively. Increasing Qp caused gradual increases in the parenchymal parameters; the changes became statistically significant at 10 ml/min for G and 12.5 ml/min for H. The maximal relative changes were 35.8 \pm 4.1 and 19.4 \pm 4.1\% for G and H, respectively. The relatively greater increases in G resulted in small, but statistically significant, increases in \( \eta \) from Qp = 7.5 ml/min. Although there was a tendency for Rv to increase with Qp, this effect was not statistically significant.

Figure 4 illustrates the parameters at different levels of Qp when Pcest was kept at 20 mmHg. No edema developed at high Qp levels, whereas marked increases in weight gain were observed at Qp = 5 and 2.5 ml/min (note that the experiments were started at Qp = 30 ml/min). Monotonous and statistically significant elevations in Raw were obtained with decreasing Qp, with
a maximal relative change of 48.3 ± 13.5% before edema development. No systematic changes were observed in Iaw with changing $Q_p$. G and H exhibited monotonous increases with decreasing $Q_p$; significant changes were observed in both parameters from 15 ml/min, and the maximal elevations before edema development were 29.2 ± 7.8 and 28.2 ± 6.4% for G and H, respectively. Alteration of $Q_p$ did not have a significant effect on $\eta$ or $R_v$.

Figure 5 depicts the relationships between Ppa and weight gain and between Ppa and the mechanical parameters for all the lungs in the groups, where the vascular pressures (Ppa and/or Pla) or $Q_p$ were altered. Pooling of the data points obtained in the three groups did not reveal any clear relationship between Ppa and weight gain. Likewise, no correlation was obvious between Ppa and the lung mechanical parameters.
The relationships between Pla and weight gain and between Pla and the lung mechanical parameters for all the lungs in which the pulmonary hemodynamics were altered are outlined in Fig. 6. Weight gain remained at around zero at Pla \(10\) mmHg, and it was generally positive at Pla \(>20\) mmHg. No clear effects of Pla on Raw were evident at low Pla levels; however, systematically higher Raw values were observed at higher Pla. G and H were minimal at Pla \(7–10\) mmHg, whereas these parameters were markedly higher at lower and higher Pla.

**DISCUSSION**

In the present study, the flow and pressures in the pulmonary circulation were varied independently, and
the resulting changes in the airway and parenchymal mechanics were systematically investigated. We observed significant changes in the mechanical properties of the airways and the parenchyma in response to acute alterations of the pulmonary hemodynamic parameters, with characteristically different patterns of change in the various groups.

Methodological issues. The isolated, perfused rat lung model offers ideal conditions under which to investigate how acute changes in pulmonary hemodynamics alter the mechanical conditions of the lungs. In this experimental setting, each pulmonary hemodynamic parameter can be altered independently, and the acute changes in lung mechanics can be assessed in the absence of confounding systemic hormonal and neurogenic influences (31).

It has previously been demonstrated that it is primarily the pressure in the pulmonary capillaries that
Fig. 5. Relationships between Ppa and edema index (weight gain), Raw, G, and H in 3 groups. ○, Altered pulmonary capillary pressure during constant Qp; △, altered Qp during constant pulmonary capillary pressure of 10 mmHg; □, altered Qp during constant pulmonary capillary pressure of 20 mmHg.

Fig. 6. Relationships between Pla and edema index (weight gain), Raw, G, and H in 3 groups. ○, Altered pulmonary capillary pressure during constant Qp; △, altered Qp during constant pulmonary capillary pressure of 10 mmHg; □, altered Qp during constant pulmonary capillary pressure of 20 mmHg. Solid lines, 2nd-order polynomial fits.
determines the pulmonary capillary filtration coefficient (14). Accordingly, the effective pulmonary capillary pressure (Pc_{eff}) influences the capillary permeability (16) and is expected to affect the viscoelastic properties of the alveolar wall via a direct mechanical interdependence. Direct techniques to measure P_{eff}, such as micropuncture (4) or analyses of the pulmonary occlusion pressure profile (17), are very difficult in the lungs of small rodents. We therefore applied an indirect technique in the present study and estimated P_{eff} by calculating P_{est} from P_{pa} and P_{la} (14). Because this approach assumes that the venous resistance is \( \frac{44}{4} \% \) of the total Rv (14), it is possible that changes in Rv might have biased the estimation of P_{eff} (8). We note, however, that Rv was fairly stable throughout the experiments, except when an extremely low P_{la} was associated with a subnormal P_{pa} (Fig. 2).

The aim of the study was to investigate the effects of acute changes in the pulmonary hemodynamics on the mechanical properties of the lungs. Changes induced in the pulmonary vasculature by chronic heart-lung diseases, such as thickening of the pulmonary vasculature (30), did not fall in the scope of this study. Although acute and chronic effects are involved in clinical situations, the immediate improvement in lung function after surgery for congenital heart diseases (1, 3, 15, 20, 22, 24) suggests that acute effects play a significant role in the compromised lung function.

Relationship between P_{pa} and lung mechanics. We did not find any coherent relationships between the lung mechanical parameters and P_{pa} (Fig. 5); the normal airway and parenchymal properties were maintained even at very high levels of P_{pa} (40–45 mmHg). Consequently, our data suggest that P_{pa} is not the primary variable determining the mechanics of the airways or the parenchyma after acute changes in pulmonary hemodynamics.

Previous studies led to inconsistent conclusions as concerns the relationship between P_{pa} and lung mechanics. Some investigations have revealed a clear correlation between an elevated P_{pa} and the subsequent changes in the mechanical properties of the lungs (2, 13, 23, 27, 28), although the increases in P_{pa} were always associated with increases in pulmonary venous pressures in those investigations. Other studies failed to detect any change in lung function in the presence of an elevated P_{pa} (3, 6, 7, 11, 22, 26). The findings of the present study are in accord with the latter observations, demonstrating only poor quantitative relationships between P_{pa} and the lung mechanical parameters.

Relationship between P_{la} and lung mechanics. Plots of the parameter values against P_{la} reveal consistent relationships between the postcapillary pressure and the mechanical conditions of the airways and the parenchyma (Fig. 6). At low pulmonary venous pressures, no adverse effect on the airway mechanics was observed, whereas the parenchymal parameter values increased. At high P_{la} levels, the decreases in the overall airway diameter are associated with impairments of the parenchymal viscoelastic properties.

To our knowledge, the present study is the first to demonstrate an elevated parenchymal impedance at P_{la} levels lower than physiological. The mechanism by which a decreased P_{la} affects lung mechanics can only be hypothesized. The absence of a venous afterload pressure in the pulmonary circulation may result in a decreased tension in the pulmonary microcirculation, which may lead to an unstable geometry of the alveolar space. Without the tethering effect of the tense microvasculature, the alveolar units will tend to lose their geometric stability, which may lead to increased G and H. However, our finding that Raw was not elevated at low P_{la} levels suggests that these changes occurred only in the alveolar units and were not reflected in the measurements of Raw, a parameter determined by the geometry of the bronchial tree.

The increases in G and H with P_{la} above physiological levels may be attributed to different phenomena. Deteriorated parenchymal mechanics may result from the increased tension of the pulmonary microvasculature, which may lead to an increased stiffness and dissipation of the parenchyma via mechanical attachment (2). Additionally, the decreases in functional lung volume at high vascular pressures might also have contributed to these changes (11); the blood-filled pulmonary microvasculature might have partially occupied the functional alveolar air space. Finally, the edema development further amplified the deterioration in airway and parenchymal mechanics when increases in weight gain were observed.

Conflicting results have been reported on the effects of an altered P_{la} on lung mechanics. In agreement with our findings, the primary importance of the pulmonary venous pressure in the compromised lung function has been recognized by virtue of experimental studies performed on dogs (6, 19, 21). Nevertheless, these studies were limited to extremely high P_{la} levels (30–35 mmHg), and hence edema development was likely to be the major contributor to the observed changes in CL and Rt (6) or in Raw (19, 21). In contrast, no clear relationships were observed between P_{la} and CL (2, 13) or between P_{la} and Raw (13) in children with congenital heart disease. This controversy can most probably be attributed to the relatively small range of P_{la} encountered in clinical studies (9–16 mmHg in Ref. 13), which leads to the rather moderate changes being undetected.

Q_{p} and lung mechanics. Our experiments involving changing Q_{p} revealed that the mechanical properties of the lungs depend on the pressure conditions maintained in the pulmonary vasculature during these maneuvers. In the lungs where P_{ca} was maintained at 20 mmHg, the increases in Raw paralleled the increases in P_{la}. Moreover, changes in Q_{p} induced quantitatively similar, but opposite, changes in the parenchymal mechanics at P_{ca} of 10 and 20 mmHg (Figs. 3 and 4). Although the sequences of Q_{p} levels were also opposite in these groups, a role of the experimental time in these changes can be excluded, since the mechanical
parameters in the control group were stable. It seems far more likely that the changes in \( P_{\text{a}} \) are responsible for this finding, and the relationships between \( P_{\text{a}} \) and the lung mechanical parameters explain this phenomenon as follows.

As clearly demonstrated in Fig. 6, the range of decreasing \( P_{\text{a}} \) values associated with increasing \( Q_{\text{g}} \), at \( P_{\text{est}} = 10 \text{ mmHg} \) corresponds to conditions of no change in weight gain or Raw, while decreases in \( P_{\text{a}} \) cause increases in G and H. In contrast, the impedance parameters of the lungs in which \( Q_{\text{g}} \) was altered at \( P_{\text{est}} = 20 \text{ mmHg} \) are situated at the top of the U-shaped curve, where increasing \( P_{\text{a}} \) causes increases in Raw, G, and H. Consequently, our results indicate that \( P_{\text{a}} \), and not \( Q_{\text{g}} \), triggers the changes in the mechanical properties of the lungs. In this regard, it is noteworthy that at extremely high flows (5 times higher than normal) lung mechanics remain entirely normal, even if these \( Q_{\text{g}} \) values are associated with considerable elevations in \( P_{\text{pa}} \), provided that the \( P_{\text{a}} \) values are physiological.

Previous studies have emphasized the importance of an increased \( Q_{\text{g}} \) in the altered pulmonary mechanics (9, 13, 22). In other reports, it was found that an elevated \( P_{\text{a}} \) affects lung mechanics only when high pulmonary vascular pressures are also present (2, 3, 20, 26). The conclusions of all these previous investigations were based on measurements in children with various congenital heart diseases (2, 3, 13, 20, 22, 26) or after administration of a pulmonary vasodilator drug (9). Nevertheless, because the changes in \( Q_{\text{g}} \) were always associated with changes in pulmonary pressures in those studies, it is difficult to identify the separate roles of the abnormal pulmonary circulatory pressure and flow from the measurements. Indeed, in agreement with our findings, changes in \( Q_{\text{g}} \) alone without modification of the pressure conditions in the pulmonary circulation proved to have only minor effects on the lung mechanics under experimental conditions (6).

**Summary and conclusions.** In an isolated-perfused rat lung model, we demonstrated that acute changes in pulmonary hemodynamics lead to characteristic alterations in the mechanical properties of the airways and the parenchyma. The pulmonary hemodynamics variable to which changes in edema index and lung mechanical parameters can be related most consistently is \( P_{\text{a}} \). Airway narrowing occurs only if \( P_{\text{a}} \) exceeds physical values, whereas the parenchymal impedance parameters are minimal in the normal physiological range of \( P_{\text{a}} (7–10 \text{ mmHg}) \) and exhibit parallel increases at lower and higher pressures. Because it is possible in clinical situations to alter the pulmonary hemodynamic parameters relatively independently by means of selective pharmacological interventions, the results of the present study indicate that maintenance of the physiological range of pulmonary venous pressure is a prerequisite for the optimal mechanical conditions of the lungs.

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