Mechanics of Breathing During Anesthesia.
2. The Influence of Airway Adequacy

Martin I. Gold, M.D., and Martin Helrich, M.D.*

Pulmonary compliance ($C_L$) and resistance ($R_L$) were measured simultaneously in 13 supine patients prior to operation in both awake and anesthetized states. During anesthesia three airway situations were compared: (1) mask, no airway, (2) mask, oral airway, and (3) endotracheal airway. During mask anesthesia $R_L$ was 123 per cent above the control without oral airway, 55 per cent above the control with oral airway, and with tracheal intubation $R_L$ decreased to 18 per cent below the control. During periods of increased $R_L$ with mask, such “subtle” obstruction was clinically undetectable, not accompanied by decreased tidal exchange. The primary reason for elevated $R_L$ during mask anesthesia was due to increases in upper airway resistances. Compliance fell approximately 15 per cent during anesthesia, remained at a depressed level and was uninfluenced by the type of airway or its adequacy.

Normal pulmonary mechanics may become abnormal in the spontaneously breathing anesthetized patient as evidenced by decreased compliance and increased resistance.\textsuperscript{1-8} In the spontaneously breathing patient, hypoxemia has been demonstrated. The reason proposed is gradual atelectasis with venous-arterial shunting.\textsuperscript{8-10} Increased work of breathing, subsequent overproduction of carbon dioxide and demand for more oxygen contribute further to deviation from the normal.\textsuperscript{4, 5} However, little is known about simultaneous behavior of the two components of pulmonary mechanics, pulmonary compliance ($C_L$) and resistance ($R_L$). In addition, little is known about the influence of the airway on mechanics during anesthesia.

An obstructed airway offers increased resistance to breathing. In this instance, how does compliance change and how important is the degree of airway obstruction? Complete obstruction, such as from laryngospasm, results in neither tidal exchange nor gas flow. Partial obstruction results in decreased tidal exchange, decreased gas flow rates, and increased changes in both airway and transpulmonary pressures. Do lesser degrees of obstruction exist in which an adequate tidal exchange is present? We believe that they do and it is the purpose of this investigation to relate the type of airway and its adequacy to simultaneous compliance and resistance during general anesthesia in supine, spontaneously breathing man. We propose that these lesser degrees of obstruction be called “subtle obstruction” since they are clinically undetected and yet may significantly increase work of breathing in spontaneously breathing patients.

Experimental Method

The technique of measuring transpulmonary pressure ($P_T$), flow rate ($V$), and tidal volume ($V_T$) continuously via a pneumotachograph and integrator in the supine, anesthetized patient has been described.\textsuperscript{11} Instrumentation included appropriate transducers, a carrier-amplifier, oscilloscope, and rapid-writing attachment. $C_L$ and $R_L$ were calculated from a series of breaths (average 25) from which changes in $P_T$, $V$, and $V_T$ were obtained. Figure 1 demonstrates the method of calculating expiratory compliance and isovolume resistance. In this present study such measurements were made prior to operation in the conscious state and during the spontaneously breathing anesthetized state when the type of airway was varied.

Thirteen patients were premedicated with 100 mg. of pentobarbital and 0.4 mg. of scopolamine intramuscularly approximately 1 hour prior to entering the anesthesia labora-

* Department of Anesthesiology, University of Maryland School of Medicine, Baltimore.

Accepted for publication July 7, 1965. This investigation was supported by Public Health Research Grant HE-06429 from the National Institutes of Health.
TABLE 1. Pulmonary Compliance (C_L) and Resistance (R_L) as Influenced by Type of Airway During Anesthesia

<table>
<thead>
<tr>
<th>Patient</th>
<th>Sex</th>
<th>Age</th>
<th>Height (inches)</th>
<th>Weight (lbs)</th>
<th>Primary Anesthetic Agent</th>
<th>Thiopental (mg.)</th>
<th>AWAKE CONTROL</th>
<th>Anesthetized</th>
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<td>Methoxyflurane</td>
<td>375</td>
<td>0.14</td>
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</tr>
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</table>

Range: 22–112, 58–196, 50–375
Mean: 37, 66, 148

Results

Table 1 lists pertinent descriptive data and the changes in C_L and R_L as influenced by type of airway in 13 patients. Four airway situations were compared: (1) awake, mask, control; (2) anesthetized, mask, no oral airway; (3) anesthetized, mask, oral airway; and (4) anesthetized, endotracheal airway.

During the second situation (anesthetized, mask, no airway), R_L more than doubled while the C_L decreased approximately 20 per cent (fig. 2). During the third situation (anesthetized, mask, oral airway), R_L remained elevated at approximately 50 per cent above the control but decreased upon insertion of oral airway; C_L remained at the previously depressed level. During the fourth situation (endotracheal airway), R_L fell to below the control level while the C_L remained at the previously depressed level.

An example of how the R_L and C_L changed during general anesthesia is demonstrated in figure 3. Corresponding changes in pressures, flows, and tidal volumes have been arranged in chronologic order. This patient had normal measurements for awake R_L and C_L. Anesthesia was induced with halothane-nitrous oxide-oxygen; and during 20 minutes of mask anesthesia, this patient developed an R_L ranging from two to three times that of the control value. With insertion of the oral airway and, subsequently, tracheal intubation, R_L fell to and remained below the control level. C_L fell during anesthesia although it increased when both oral airway and endotracheal tube were inserted, with a single decrease at 20 minutes. C_L also increased to above the control at about 40 minutes of anesthesia at which time R_L was at its lowest. The relationship between changes in V_T and C_L should be noted.

Discussion

The absolute C_L and R_L figures found in this study are low and high, respectively, when compared with data from conscious subjects in the sitting position. It has been accepted that esophageal pressure swings in the supine position are reasonably accurate although absolute pressure may be inaccurate. Changes in C_L and R_L (including deviations from the control) are believed to be quite real. There are two possible reasons for these apparent deviations in C_L and R_L from accepted norms: (1) high absolute esophageal
pressures in the supine position produced by
the weight of the heart on the intraosophageal balloon; (2) endotracheal tube resistances
(at a 40 liters/minute flow, approximately 1
cm. of water/liter/second) were not
subtracted. The absolute figures when compared
with CL and RL measurements in the literature
in supine, anesthetized humans show a striking similarity.1-5 Because of this and because
changes in CL and RL, as influenced by the
airway, were sought we believe the great
deviations from the control figures are
particularly significant.

The significant findings in the present
investigation center about the influence of the
endotracheal tube and changes in RL. During
mask anesthesia 12 of 13 patients without
oral airway and 10 of 13 with oral airway
demonstrated increased RL although such in-
creases were not clinically diagnosed. Tidal
exchanges during this period of obstruction
(which we have termed "subtle") remained
adequate although decreased (fig. 2). Only
when the endotracheal tube was inserted did
the increased RL fall to the awake, control
level in all 13 patients. This increase in RL
involved upper airway resistance primarily be-
cause it was reduced significantly with inser-
tion of the endotracheal tube. This is because
the elevated RL during mask, no airway anes-
thetasis and oral airway anesthesia was reduced
to 18 per cent below the control level with
tracheal intubation. Recent investigations
indicate that total airway resistance in awake,
sitting subjects at functional residual capacity
may be divided into upper and lower com-
ponents, both of which contribute approxi-
mately 50 per cent to the total.13,14 Wu,
Miller and Luhn1 had patients whose RL was
lower after tracheal intubation than during
the awake, control.

There are many possible causes of ob-
structed airway in the supine patient anes-
thetized with mask. Fink has suggested three
mechanisms referable to the upper airway in-
cluding reflex and passive closure of both
larynx and glottis.15 Alinearity of the flow-
pressure relationships in the human lung in the
mid-range of lung volume has been demon-
strated to result primarily from upper airway
resistance.16 It seems reasonable to conjecture
that upper airway resistance contributed sig-
ificant changes in pulmonary compliance (CL)
and resistance (RL) in 13 patients as influenced by
type of airway and anesthesia.

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**Fig. 1.** Modified from Amdur, M. O. and Mead,
J.: Mechanics of respiration in unanesthetized

**Fig. 2.** Changes in pulmonary compliance (CL)
and resistance (RL) in 13 patients as influenced by
type of airway and anesthesia.
nificantly to the total resistance elevation during mask anesthesia so that prolonged periods of such "subtle airway obstruction" during anesthesia would prove harmful.

The $C_L$ changes during anesthesia as reported were less labile and dramatic than $R_L$ changes and quite independent of the influence of airway or its adequacy. In general $C_L$ remained depressed regardless of airway at about 20 per cent below the control level. Decreased $C_L$ during anesthesia has been related to relative hypoxemia during both spontaneous and constant volume intermittent positive-pressure breathing. The cause of this aberration is unknown but the premise that atelectasis occurs has been suggested. The reduction in ventilation-perfusion ratio that follows causes a relative venous to arterial shunt leading to lowered arterial $P_{O_2}$. Another factor whose role is as yet unclear is surface tension. Higher pressures are necessary to inflate collapsed alveoli than to keep open alveoli uncollapsed; this may be related to surface tension phenomena.

The relationship between decreased $V_T$ and decreased $C_L$ during anesthesia has been demonstrated. It has never been conclusively shown but there is reason to believe that in supine, anesthetized man FRC decreases. Lowered FRC has been correlated with a decrease in $C_L$ during both deep and shallow breathing in conscious man. Compliance has been demonstrated to decrease significantly in conscious, sitting volunteers whose FRC was decreased by chest strapping to one liter below the control level. These subjects also demonstrated increased $R_L$ and evidence of shunting.

Observation of changes in $C_L$ and $R_L$ in chronologic fashion demonstrated that while some patients exhibited a positive relationship between changes in simultaneous $C_L$ and $R_L$,
others had negative correlations. In general, changes in $C_L$ and $R_L$ have been accepted as being unrelated unless extreme increases in $R_L$ occur as during true bronchospasm or extremely rapid rates of breathing.  

Summary and Conclusions

Pulmonary resistance and compliance measurements were made simultaneously in 13 supine patients during an awake, control period and again during anesthesia as varied with mask-no airway, mask-orificial, and endotracheal airway. Resistance ($R_L$) proved to be more labile than compliance ($C_L$). $R_L$ was 123 per cent above the control value during mask, no airway anesthesia. These patients' airways were usually not overly obstructed. Rather, this obstruction was clinically undetected and not accompanied by decreased tidal exchange. With insertion of the oral airway this elevated $R_L$ was lowered, but only to a level 55 per cent above the control value.

In all patients, with insertion of the endotracheal tube, $R_L$ fell to a mean figure of 18 per cent below the control level. It is concluded that the endotracheal tube decreased the elevated upper airway resistance (as contrasted to lower airway resistance) during mask anesthesia.

Compliance fell approximately 15 per cent during anesthesia and was uninfluenced by the type of airway or its adequacy.

The following individuals contributed significantly to this investigation: Holcombe Hurt, Jr., M.D., Michael Ashman, M.D., Lillian Chambliss, A.B., Barbara Eerdigh, R.N., Martin Quinn.

References