SOME OBSERVATIONS ON DYNAMIC LUNG COMPLIANCE DURING INTERMITTENT POSITIVE PRESSURE RESPIRATION

by

W. E. WATSON*

Department of Neurology, Churchill Hospital, Oxford, England

Lung compliance is the volume of air that can be introduced into the lungs by a unit change in transpulmonary pressure, and is the reciprocal of the elastic resistance. In this investigation, lung compliance was measured when the pattern of ventilation imposed upon totally paralyzed conscious patients was varied. There were five patients, each of whom had been tracheotomized; two of these were suffering from poliomyelitis, two from polyneuritis, and one from injury to the cervical spine.

METHODS

Transpulmonary pressure was measured at the instants at which there was no airflow between the respiration pump and the patient. It was derived by subtracting intrapleural pressure from tracheal pressure.

Tracheal pressure was measured at the external end of the tracheotomy tube.

Oesophageal pressure was measured by the method of Dornhorst and Leathart (1952), and was used to represent intrapleural pressure.

Airflow between the patient and the respiration pump was measured with a pneumotachograph especially designed to have a low dead-space (Opie, Spalding and Stott, 1959) and the instants of "no flow" were derived from the record obtained.

All pressures were measured with capacitance transducers and were recorded on a four-channel direct-writing pen unit. The pens were 16 cm long, worked in an arc of 4 cm and had a peak-to-peak response time of 0.07 second. The paper speed usually employed was 25 mm/second.

Tidal volume was measured with a Wright anemometer of known accuracy.

Each patient received intermittent positive pressure respiration (IPPR) from an experimental respiration pump during the investigation (Watson, Spalding and Smith, 1962). The imposed ventilatory frequency was 13/minute. A tidal volume within the range 550 to 650 ml was employed on all occasions. Lung compliance was measured under four circumstances. Firstly, the duration of inspiration was altered within the range 0.5 to 2.7 sec.; this was achieved on some occasions by altering the period allowed for inspiratory airflow, and on other occasions by introducing a variable period of breath-holding after a constant short duration of inspiratory airflow.

Secondly, a subatmospheric tracheal pressure of 15 cm H₂O was applied throughout expiration. Thirdly, the chest was prevented from returning to its resting position at the end of expiration by immersing the air outlet of the respiration pump to a known depth in a column of water. Fourthly, the imposed inspiratory airflow pattern was altered at a constant duration of inspiration by changing the imposed tracheal positive pressure waveform.

Comparison of lung compliance under different circumstances of pulmonary ventilation was completed in each patient within 2 to 4 weeks. Within this time different patterns of pulmonary ventilation were investigated in a random manner. No systematic change of lung compliance was found in any patient within the period of investigation.

Subjects.

Five totally paralyzed conscious patients were investigated. Each patient normally received IPPR from a Radcliffe respiration pump (Russell et al., 1956) through a cuffed tracheotomy tube (Spalding and Smith, 1956) which provided an
airtight seal in the trachea. All patients lay supine while measurements were made, and tracheobronchial secretions were aspirated before each estimation. The lungs of all patients were clinically and radiologically normal.

RESULTS

Duration of inspiration.
Figure 1 expresses lung compliance graphically against the duration of inspiration. A “square” tracheal positive pressure waveform was used at all durations of inspiration. The lung compliance increased markedly when the duration of inspiration was prolonged from 0.5 to 1 second. This increase in lung compliance was found both when inspiration was prolonged by increasing the duration of inspiratory airflow, and when a variable period of breath-holding was employed after a constant period of inspiratory airflow lasting 0.5 second.

Subatmospheric expiratory tracheal pressure.
The results obtained in all patients were similar, and those shown in figure 2 are typical. When a subatmospheric tracheal pressure of 15 cm H₂O was applied throughout expiration the lungs became less compliant. This reduction of compliance was greatest when the duration of inspiration was short.

Obstructed expiration.
The effect of obstructing expiration with elevation of the end-expiratory intrathoracic pressure could be investigated only in two patients as the others complained of chest pain or faintness. In both patients the lungs become slightly more compliant when the end-expiratory tracheal pressure was increased within the range 0 to 5 cm H₂O (fig. 3).
Pulmonary ventilation pattern.

Three basic inspiratory airflow patterns were investigated (Watson, Spalding and Smith, 1962). In the first the peak airflow occurred at the beginning of inspiration: this airflow pattern was created by a "square" tracheal positive pressure waveform (waveform 1, fig. 4). The second tracheal positive pressure waveform (waveform 2, fig. 4) gave a constant flow rate throughout the inspiratory phase of the respiratory cycle. The third airflow pattern reached a peak at the end of inspiration and was created by a "slowly rising" tracheal positive pressure waveform (waveform 3, fig. 4).

Lung compliance was measured with each of these three waveforms at durations of inspiration of 1 second, 1.6 seconds and 2.7 seconds. Results obtained from investigation of a typical patient are shown in figure 4. No change was found in lung compliance when the imposed tracheal positive pressure waveform was altered at a given duration of inspiration in any patient investigated.

DISCUSSION

Respiratory pressure changes measured in the oesophagus are not identical with those in the pleural cavity when the patient is in a supine position (Mead and Gaensler, 1959; Knowles, Hong and Rahn, 1959; Ferris, Mead and Frank, 1959), and falsely low values for lung compliance may be obtained if oesophageal pressure changes are employed for its estimation. In this investigation, oesophageal pressure changes were measured as representing changes in intrapleural pressure, as a series of values in a given patient lying in a constant position was required. It is possible that all the values obtained were lower than the true compliance, but it is believed that
changes in lung compliance found when the imposed pattern of pulmonary ventilation was altered represented a true change in compliance.

**Duration of inspiration.**

The dynamic lung compliance increased when the duration of inspiration was prolonged from 0.5 to 1 second either by prolongation of the inspiratory airflow period or by introducing a period of breath-holding after a constant inspiratory flow period. It is possible that this rise in compliance was due to intrapulmonary redistribution of the inspired gas. When inspiration lasted 0.5 second only, the air may have been maldistributed with preferential inflation of those lung units having the lowest individual airway resistance. When inspiration was prolonged, progressive recruitment of other lung units probably occurred. McIlroy (1952) found a progressive rise in compliance when excised lungs were left inflated. The progressive recruitment of lung units observed at thoracotomy when positive airway pressure is sustained, is familiar to most anaesthetists.

**Subatmospheric expiratory tracheal pressure.**

When a subatmospheric tracheal pressure was employed during expiration, both tracheal and oesophageal pressures measured at the end of expiration were reduced, indicating that a decrease in functional residual capacity had occurred. Mead and Collier (1959) demonstrated that the lungs of an anaesthetized dog became less compliant after negative pressure breathing. They attributed this to surface tension acting at the gas-liquid interface rendering some lung units unstable at the lowered functional residual capacity, so that collapse occurred. At autopsy they demonstrated patchy collapse in the lungs of anaesthetized dogs who had received negative pressure ventilation. It is probable that the observed decrease in lung compliance found in man when a subatmospheric tracheal pressure was employed during expiration was due to similar patchy collapse. The considerable pressure required to reinflate a collapsed lung was noted by Dixon and Brodie (1903).

The importance of change in pulmonary blood volume in contributing to the observed fall in lung compliance when a subatmospheric tracheal pressure is imposed is uncertain. Although pulmonary blood volume is probably increased as a result of reducing the mean intrathoracic pressure (Fenn et al., 1947), Frank, Radford and Whittenberger (1959) have demonstrated that distension of the pulmonary vessels of excised lungs has no marked effect on lung compliance.

**Obstructed expiration.**

Slight increase in lung compliance was found when the end-expiratory tracheal pressure was increased. As the end-expiratory oesophageal pressure was also raised, it is very probable that an increase in functional residual capacity occurred. This may have prevented collapse of some lung units which became unstable at the end of normal expiration as a consequence of surface tension acting at the gas-liquid interface.

Elevation of the mean intrathoracic pressure of the lungs reduces the vascular capacity of the lungs (Burton and Patel, 1958) but the degree to which this would contribute to an increase in lung compliance is uncertain.

**Tracheal positive pressure waveform.**

No change was found when the imposed tracheal positive pressure waveform was altered at a given duration of inspiration between 1 and 2.7 seconds. This may indicate that adequate time was available for most of the inspired gas to become redistributed within the lungs when the duration of inspiration exceeded 1 second, and that the inspiratory flow patterns investigated did not markedly affect the final intrapulmonary gas distribution.

**SUMMARY**

Dynamic lung compliance was measured in five conscious totally paralyzed patients when different patterns of pulmonary ventilation were employed. Shortening the duration of inspiration from 1 to 0.5 second resulted in a decrease in lung compliance.

A subatmospheric tracheal pressure applied throughout expiration caused the lungs to become less compliant.

Increasing the functional residual capacity caused a slight increase in compliance in the two patients investigated.

Alteration of inspiratory flow pattern at a given duration of inspiration was not associated with change of lung compliance.
ACKNOWLEDGMENTS

I am greatly indebted to Dr. W. Ritchie Russell, Dr. J. M. K. Spalding and Dr. A. Crampton Smith for the opportunity to study patients under their care, and for research facilities. Dr. E. Seelye helped in the preparation of the paper.

REFERENCES


LIVERPOOL SOCIETY OF ANAESTHETISTS

The Combined Meeting with the Anaesthetic Section of the Manchester Medical Society will be held at 8 p.m. on Thursday, April 12, 1962, at the Staff House, Manchester University.

Speakers:

Dr. J. RAVENTOS: Some Aspects of Fluothane Anaesthesia.

Dr. J. S. ROBINSON: A New Method of Assessing Premedicant Drugs.