Respiration Physiology (1972) **16**, 175–178; *North-Holland Publishing Company, Amsterdam*

SURFACE SPREADING OF LUNG ALVEOLAR SURFACTANT

RICHARD M. MENDENHALL

Department of Health, Education, and Welfare, Public Health Service, National Institute for Occupational Safety and Health, 1014 Broadway, Cincinnati, Ohio 45202, U.S.A.

Abstract. Surfactants tend to spread over and reduce equally the surface tension of a surface. Indications were sought of the rate of spreading of lung alveolar surfactant in the presence of known differentials of surface tension. It was found to spread and abolish surface tension differences at a rate measured in centimeters/second whether the initial surface tension differential was relatively high (35 dynes/cm) or low (15 dynes/cm). Alveolar lung has been thought to be stabilized by maintenance of surface tensions at values which remain directly proportional to alveolar size. However, groups of alveoli of varying sizes are contiguous and, forming a single surface, possibly act as a unit with respect to surface tension because of rapid equalization of differences in surface tension. On the other hand, the equilibrium surface tension of lung alveolar surfactant is less than the equilibrium surface tension of material found elsewhere in the lung. Combining this fact with the tendency of surfactants to spread from areas of lower to areas of higher surface tension indicates that lung alveolar surfactant does originate in the alveoli and could act as an agent to remove substances from lung alveoli to the ciliated part of the lung structure.

Alveolar surfactant
Lung stability
Removal of particulates
Surface tension
Tracheal surfactant

A highly surface-active material, termed lung alveolar surfactant (LAS), is obtained as foam from mammalian lung (Pattle, 1955; Mendenhall and Mendenhall, 1964). It is thought to originate in cells on the surfaces of lung alveoli (Buckingham, McNary, Jr. and Sommers, 1964), to function primarily at an air-liquid interface in these alveoli, and to stabilize the architecture of lung tissue as a result of its surface activity (Pattle, 1955; Clements, Brown and Johnson, 1958). The effect of surface activity on lung stability is thought to be mediated through the laws of capillarity (Clements *et al.*, 1958) which would require surface tension (γ) in alveoli to be directly proportional to their size.

The structure of that part of the lung where alveoli are the dominant feature

Accepted for publication 10 June 1972.

places the surfaces of alveoli of varied sizes in mutual contact. This fact suggests that the foregoing concept be reconsidered in view of the tendency of surface-active substances to expand from areas of lower γ to areas of higher γ. Accompanying the expansion should be an equilibration of γ over all areas which form a continuous single type of surface, hence the increased stability of smaller alveoli producible by relatively lower γ might not arise or might vanish if it did arise.

Methods

Equipment to permit development of experimental evidence needed to test these concepts consists of a surface balance trough divided by a gate into 2 cells, A and B, each of which represents a lung alveolus (Mendenhall, 1971). The discrete cell areas are made to vary sinusoidally with time through movement of defining boundaries which are designed to prevent spread of LAS beyond them (Mendenhall, Mendenhall, Jr. and Tucker, 1966). The γ of each cell can be measured by the vertical pull technique and recorded as a continuous function of time or area. When the gate is opened, the total area of the combined cells is not changed, but becomes one area.

In the experiments described here the liquid in the trough was distilled water (Mendenhall *et al.*, 1966); the area of each cell was varied sinusoidally at 10 cycles/minute; and γ was recorded as a function of time. LAS was obtained as described elsewhere (Mendenhall, Sun and Mendenhall, Jr., 1967).

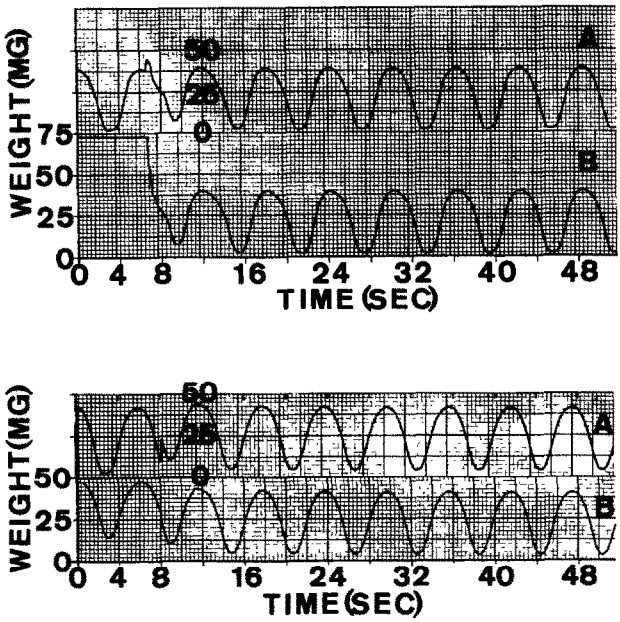
Results

Data photographed for fig. 1 were produced as follows. Excess LAS was placed in cell A (fig. 1A) and nothing was added to cell B (fig. 1B). Recording was begun at maximum area in both cells, maximum γ in cell A, and constant γ (clean surface) in cell B. The moment the gate was opened is shown in fig. 1A as an abrupt rise in γ at about 6.5 sec.

Figure 2 is a photograph of data produced when LAS was placed in both cells: an excess in cell A (fig. 2A); not enough in cell B (fig. 2B) to give a true minimum γ at minimum area. The moment the gate was opened is depicted by the abrupt rise in γ in fig. 2A at about 8 sec.

Maximum and minimum area of both cells and of the combined cells for both experiments are given in the table. Also listed are the ratios of maximum:minimum area and the time required to reach a common dynamic γ after opening the gate. The technique is precise since 2 different sets of sensing and recording equipment (except for a single time axis) yielded results which can be superimposed at and after intercellular equilibration of γ.

The γ differential between cells at the moment the gate was opened was about 35 dynes/cm in the first experiment, and 15 dynes/cm in the second. Abrupt changes in γ occurred when the gate was opened and the time required to reach a common γ was small in each case (see table 1). Similar conditions in real alveoli might result in even faster equilibration because the areas involved are smaller. Briefly, the model is conservative in this application.



Figs. 1 and 2. Records of relationship between surface tension and time of two contiguous cells, A and B, before and after opening a separating barrier at about 6.5 sec (fig. 1) and 8 sec (fig. 2). Abrupt rise of surface tension in cell A in both figures accompanied opening of the barrier and was caused by spread of LAS from cell A to cell B. Maximum and minimum areas of each cell and of the united cells are given in the table. Area was varied continuously and sinusoidally at 10 cycles/min. Perimeter of the frosted glass plates was 1.006 cm each.

TABLE 1

Maximum and minimum area of cells A and B and of the combined cells.

Fig.	Gate	Max. area (A, cm^2)	Min. area (a, cm^2)	Ratio A:a	Equilibration time (sec)*
1A	closed	59.15	36.55	1.62:1	—
1B	closed	76.50	53.90	1.42:1	—
1	open	135.7	90.5	1.50:1	1.4
2A	closed	49.5	34.8	1.42:1	—
2B	closed	72.2	57.4	1.26:1	—
2	open	121.7	92.2	1.32:1	0.4

* Time required for the newly formed single surface to achieve a common dynamic γ after opening the gate. (The time required, after opening the gate, for the two curves to become superimposeable.)

Discussion

Based upon the evidence presented here, it appears that actual γ differentials from point to point in the lung alveolar region would tend to be small; larger ones being supplanted by a net movement of the LAS away from the alveolar regions. Since the

alveolar regions are surface cul-de-sacs in the lung, a net movement away from them would constitute a flow of LAS from alveoli and on to those surfaces of the lung which incorporate a mechanical cleansing agent in the form of beating cilia.

It becomes obvious upon further consideration that the LAS, the lung's most surface-active material (Mendenhall *et al.*, 1966), must actually start its journey in the terminal units of the lung: the alveoli. Substantive evidence is thus obtained for the concept that the LAS serves as an agent to remove particulate matter, including moveable cells, from lung alveoli (Mendenhall, 1963).

Static γ of pig tracheal mucus is about 37 dynes/cm; of pig LAS, about 30 dynes/cm (Mendenhall *et al.*, 1966). It is suggested that present theories relating LAS to stability of lung tissues do not require the γ in any of the alveoli to diminish much below the latter value, and they should not require enduring differentials of γ between alveoli.

References

Buckingham, S., W. F. McNary, Jr. and S. C. Sommers (1964). Pulmonary alveolar cell inclusions: their development in the rat. *Science* 145: 1192–1193.

Clements, J. A., E. S. Brown and R. P. Johnson (1958). Pulmonary surface tension and the mucous lining of the lungs: some theoretical considerations. *J. Appl. Physiol.* 12: 262–268.

Mendenhall, R. M. (1963). Pulmonary mechanics: some physical and biochemical factors. *Arch. Environ. Health* 6: 74–79.

Mendenhall, R. M. and A. L. Mendenhall, Jr. (1964). Lung alveolar surfactant, lung elasticity, and lung stability. *Nature* 204: 747–748.

Mendenhall, R. M., A. L. Mendenhall, Jr. and J. H. Tucker (1966). A study of some biological surfactants. *Ann. N.Y. Acad. Sci.* 130: 902–919.

Mendenhall, R. M., C. N. Sun and A. L. Mendenhall, Jr. (1967). Lung alveolar surfactant and the Thomson-Marangoni effects. *Respir. Physiol.* 2: 360–374.

Mendenhall, R. M. (1971). A surface balance for the study of surfactant movement. *Rev. Sci. Instr.* 42: 878–880.

Pattle, R. E. (1955). Properties, function, and origin of the alveolar lining layer. *Nature* 175: 1125–1126.