Relationship between functional residual capacity to various body measurements in normal sheep

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Relationship of Functional Residual Capacity to Various Body Measurements in Normal Sheep

Thomas G. Mundie, Kenneth T. Dodd, and Michael Lagutchik

Abstract 1 Functional residual capacity (FRC) was determined by nitrogen washout in 55 normal sheep. Data on various external body measurements were collected which included body weight, chest circumference, chest width, body length, height, and sternum length. In addition, data on wet lung weight and wet lung weight/body weight ratio were collected on 10 of the sheep. A significant correlation was found between FRC and all measured parameters except height and sternum length. Multiple linear regression of all external body measurements showed the best correlation of FRC to body weight and body length, while the addition of chest circumference and/or chest width did not significantly improve the correlation. Significant deviation from the population was noted in three sheep (5.5%) that had lung weight/body weight ratios which were significantly lower than the rest of the population.

Functional residual capacity (FRC) is the volume of air in the lung at the end of a normal breath. It is the point at which the elastic recoil of the lungs and the chest wall balance one another. Normal FRC may be altered by several disease states or ventilatory support methods. Sheep are being used increasingly in investigations of pulmonary function when direct determination of FRC is impossible and an estimation of FRC is needed. Normal FRC values for sheep have been reported in liters (1), however, our knowledge, no equation for estimating FRC from weight or other body measurements has been reported. We sought to determine the relationship of FRC to various external body measurements, as well as to lung weight for the range of animal sizes used in laboratory studies and to establish a method of estimating FRC from external body measurements.

Materials and Methods

Fifty-five normal, Q-fever negative, mixed-bred, adult female sheep (Ovis aries) (21 to 56 kg) were acquired from a commercial source. All sheep were dewormed and quarantined for 3 weeks. They were housed indoors and feeding was maintained with standard sheep feed supplemented with hay. The sheep were closely shorn for external body measurements. The study protocol was approved by the Institutional Animal Care and Use Committee of the Walter Reed Army Institute of Research. During the conduct of the research described herein, animals were used according to established guidelines (2).

After administration of topical anesthesia (Cetacaine spray), each animal was intubated transnasally with a cuffed endotracheal tube (custom 40 cm long, 7.5 mm silicon, Bivona, Gary, IN) using a fiberoptic bronchoscope. The endotracheal tube was secured in place by role gauze. Sheep were allowed to stand in a metabolic cage but their heads were restrained by a muzzle and vertical padded bars. Before FRC determination, each animal was acclimated to the restraint and allowed to stand undisturbed in the metabolic cage for several minutes to attain resting ventilatory parameters. The process of intubation, FRC determination, and extubation took no more than 30 minutes. If animals became agitated or began to hyperventilate, they were not used. Neither food nor water were withheld from the sheep before experimentation.

The following external body measurements were made on the sheep while in the standing position. Body weight (WT) was measured using a digital floor scale: body length from the base of the tail to the nose (LGTH), following the contour of the dorsal aspect of the body measured using a cloth yardstick; height (HT) measured at mid-chest level; chest circumference (CIRCUM) measured at the end of exhalation at the level of the Xiphoid process so as not to get significant contribution from abdominal contents; chest width (WDTH) measured dorsal/ventral at the widest portion of the rib cage using X-ray calipers. While the sheep was in dorsal recumbency, the sternum length (STERNUM) was measured from the distal tip of Manubrium to the distal tip of the Xiphoid process. In addition to these external body measurements, wet lung weight (LUNG-WT) and wet lung weight/body weight ratio (LWT/BWT) were determined in 10 sheep as part of a control necropsy in other studies. Necropsy results indicated no evidence of lung injury or abnormalities.

FRC was determined by the nitrogen washout method as originally described by Darling et al. (3). Respiratory flow
was measured using a heated pneumotachometer (Model 3500, Hans Rudolf, Inc., Kansas City, MO). Inspired and expired flow was directed using a large two-way nonbreathing valve (Model 3813, Hans Rudolf, Inc.). On the inspired side a manual three-way directional stopcock valve directed inspired air from either room air or 100% O
. On the expired side, a similar 3-way valve directed expired air to either room air or a 40-liter collection bag. Air was sampled proximal to the pneumotachometer for analysis of N\textsubscript{2} concentration (FN\textsubscript{2}) using a mass spectrometer. The above described circuit was similar to previously described methods (4). Respiratory flow and FN\textsubscript{2} data were collected into a PC-based data acquisition system (CODAS, DATAQ, Inc., Akron, OH).

Separate linear regressions were performed on each measurement parameter related to FRC and the correlation coefficient (r\textsuperscript{2}) was determined. The level of significance of the linear regression was determined by a hypothesis test of the slope of the regression line. Significance was accepted at P < 0.05. In addition, multiple linear regression was performed on WT, LGTH, CIRCUM, WDTH. Andrews' sine regression weighing procedure was used to detect and exclude outlying data points. Once these outliers were excluded, multiple linear regression was performed without weighing.

**Results**

The relationship of FRC to various body measurements is shown in Figure 1 (Panels A–H). A statistically significant correlation (P < 0.05) was found between FRC and WT (r\textsuperscript{2} = 0.488), LGTH (r\textsuperscript{2} = 0.446), CIRCUM (r\textsuperscript{2} = 0.450), WDTH (r\textsuperscript{2} = 0.383), LUNG-WT (r\textsuperscript{2} = 0.766) and LWT/BWT (r\textsuperscript{2} = 0.487), but not between FRC and HT (r\textsuperscript{2} = 0.058) or STERNUM (r\textsuperscript{2} = 0.053). FRC correlated best with LUNG-WT and can be estimated from the equation:

\[
\%N_2(\text{alveolar 1}) = \text{Fraction of } N_2 \text{ in the alveolar gas initially}
\]

\[
\%N_2(\text{alveolar 2}) = \text{Fraction of } N_2 \text{ in the alveolar gas at the end}
\]

\[
N_2(\text{tissue}) = \text{Volume of } N_2 \text{ washed out of the blood/tissues (40 ml/min/kg)}.
\]
FRC (liters) = (3.34 * LUNG-WT (kg)) – 0.33.

Multiple linear regression of external body measurements WT, LGTH, CIRCUM, and WDTH showed that FRC can best be estimated from WT and LGTH using the following equation:

FRC (liters) = (0.0271 * WT (kg)) + (0.0168 * LGTH (cm)) – 1.4067

where, \( r^2 = 0.536. \)

Addition of CIRCUM and WDTH to the multiple regression equation did not significantly improve the correlation coefficient (\( r^2 = 0.538 \)). The external body measurements of three sheep (solid circles in Figure 1) did not correlate well with FRC. Andrews’ sine regression weighing procedures were used to exclude these data from all linear regressions (Panels A–G) except the linear regression of LUNG-WT (Panel H).

Discussion

Nitrogen washout determination of FRC in normal sheep was relatively uncomplicated and easily tolerated by most sheep. No significant problems were observed. For male and female adult humans, FRC has been most closely correlated with height but has also been estimated from a combination of height, weight, age and/or body surface area (4–8). In our study of sheep, the best correlation of FRC and external measurements was found with weight and length (equivalent to height in humans). For most of the sheep tested in this study, FRC was found to be significantly correlated with body weight, length, chest circumference, and chest width. It was expected that FRC in normal sheep would correlate with those body measurements which are associated with lung/chest size and not correlate with those parameters which are independent of lung/chest size. Three animals deviated significantly from the population. They had low lung weight/body weight ratios so that there was little correlation with most external body measurements but good correlation with lung weight. The wet lung weight/body weight ratio was significantly lower that the rest of the population.

Table 1 shows FRC and body weight data from this and other studies which have included control FRC data for sheep (8–17). The FRC data reported here are in general agreement with previously reported values for female sheep. The two of normal results. Am. Rev. Resp. Dis. 79.457-463.

The views of the authors do not reflect the position of the Walter Reed Army Institute of Research, the Walter Reed Army Medical Center, the Department of the Army, or the Department of Defense.

Table 1. Comparison data for functional residual capacity (FRC) and sheep body weight

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<th>Weight*</th>
<th>FRC (liters)</th>
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<tr>
<td>9</td>
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*Sheep body weight reported as mean or median value.

References


