Deuterium Oxide Dilution Kinetics to Predict Body Composition in Dairy Goats

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ABSTRACT

Body composition and D₂O dilution kinetics were studied in 15 female goats ranging from 38.0 to 70.1 kg live weight. Infrared spectrophotometric analyses of blood samples drawn during the 4 d following D₂O injections were used to estimate D₂O space. All does were slaughtered without shrinking and analyzed for dry matter, fat, nitrogen, and ash content. Estimates of D₂O space from the late slope of the dilution curve, together with live weight, were used to predict body composition.

Conclusions were 1) deuterium oxide space with live body weight accounts for about 90% of the variation in dairy goat empty body fat, empty body nitrogen, and empty body dry matter; 2) less than half the variation in empty body ash is related to live weight and D₂O space; and 3) D₂O space estimates would be biased by accelerations in water turnover.

INTRODUCTION

Goats are important to nutritionists as experimental units. They are low cost representatives of ruminant species for investigation of general nutritional phenomena. Also, expanded knowledge of specifically caprine biology is important to people who depend on goats to provide meat, milk, fiber, income, and other items of cultural value.

Observation of live animal body composition is important to students of animal energetics and investigators studying the effects of diets and additives on animal performance. Pioneering work by Reid (8) indicated that knowledge of body water content is helpful in predicting body fat, lean, and ash content. Deuterium oxide dilution techniques have been used with varying success to predict live body composition in sheep, goats, man, cattle, and dogs. Previous reports (4, 7) using D₂O and tritiated water to predict sheep and goat body composition showed some promise. Unfortunately, these early efforts were plagued by technological problems. These estimates were based on single samples of blood taken for D₂O analyses, which made them sensitive to variation due to interanimal differences in rates of mixing and water turnover. More recently, Byers (2, 3), Odwongo et al. (6), and Arnold et al. (1) described new techniques that represent significant improvements in the application of D₂O dilution kinetics to the estimation of live body composition in cattle.

The purpose of this study was to demonstrate a simple, valid method for estimating body composition in goats from late D₂O dilution kinetics and to provide information on the relationships between various chemical components in goat body compartments.

MATERIALS AND METHODS

Animals

Fifteen female goats ranging from 38.0 to 70.1 kg live weight and from 2 to 5 yr of age were group-fed a pelleted ration (69% alfalfa, 30% wheat, 1% salt) and alfalfa hay free choice. Five does were dry, and 10 were lactating (2.05 ± .83 kg/d). Three does were in the 1st mo, 3 in the 2nd mo, and 1 in the 5th mo of pregnancy while the other 8 were not pregnant. The experimental group included 8 French Alpines, 5 Nubians, and 2 Toggenburgs. Lactating does were milked by machine twice daily at 0630 and 1830 h.

Determination of Deuterium Oxide Kinetics

Beginning at 0800 h, goats were weighed to the nearest .1 kg and approximately 400 mg/kg body weight 99.8% D₂O was injected into the jugular vein. At about 5, 15, 30, 60 min, and 2, 4, 8, 12, 24, 48, 72, and 96 h after injection,
blood samples were drawn from the opposite jugular into heparin treated vacutainer tubes. The actual times of injection and sampling were recorded to the nearest 10 s. Goats had access to feed and water at all times except the 1st h after injection. Blood samples were analyzed for D$_2$O content by the method of Byers (2). The same batch of D$_2$O was used for mixing standards as was injected into goats. The logarithm (log; base 10) of the D$_2$O concentration ([D$_2$O]) was plotted against time after injection (see Figure 1). For the log-linear portions of these curves (from 24 to 96 h after injection), [D$_2$O] was regressed on time after injection. The antilog of the calculated y intercept of the resulting equation was taken to approximate the theoretical concentration of D$_2$O in the goats' body fluids if instantaneous mixing had occurred [D$_2$O]$_t_0$. The actual dose of D$_2$O (g) was then divided by the [D$_2$O]$_t_0$ and multiplied by 1000 to give an estimate in kilograms of the D$_2$O space (D20SPACE).

**Calculation of Prediction Equations**

Empty body fat, empty body nitrogen, empty body ash, and empty body dry matter (DM) were regressed on both total body weight (TBWT) and D20SPACE. Empty body weight was regressed on TBWT alone and empty body water was regressed on D$_2$O alone. Minitab (9) statistical package was used to apply these regression analyses (10).

**RESULTS AND DISCUSSION**

Table 1 presents the moisture, DM, fat, fat free dry matter (FFDM), ash, fat- and ash-free dry matter (FAFDM), N $\times$ 6.25 (crude protein), residual mass (FAFDM $-$ N $\times$ 6.25), FAFDM:N ratio, and total mass for carcass, viscera, liver, blood, and empty body. Moisture and DM are presented for ingesta and total body.

Empty body averaged 44.5% DM, which was over half (52.5%) fat. Ash averaged 19.59% of the FFDM. When the conventional nitrogen to crude protein conversion factor of 6.25 was applied, residual mass for all tissues except liver were 1.68% or less. Residual mass of liver made up 18.5% of its dry weight. Stored carbohydrate such as glycogen, proteins containing less than 16% N, accumulated experimental variations, and the sum of biases from all the measurements of liver composition probably contributed to this large residual. The FAFDM:N for liver was 7.954, indicating this fraction contained far less than 16% N and probably less than 100% protein. Viscera (known to contain mucus and other organic secretions containing less N than proteins) had a FFDM:N of 6.937. Other fractions were similar to the conventionally assumed protein:N.

**Direct Body Composition Determination**

Immediately after the last blood sample, goats were transported to an abattoir, stunned with a captive bolt shot to the head, and killed by exsanguination. The goats were then eviscerated, and the ingesta expressed by hand and scraped by knife from the viscera. Blood, ingesta, and liver were weighed, sampled, and discarded. Samples were frozen in airtight whirlpacks for further analyses. The carcass (head, hide, kidneys, and carcass without mammary gland) and viscera (balance of body with mammary gland but without liver) were frozen separately, weighed to adjust for moisture loss, and ground four times through .63-cm openings in a 50-hp Autio 801 meat grinder. This ground material was sampled in duplicate and frozen in whirlpacks for further analyses.

All samples were freeze-dried and analyzed for ether extract, N, and ash as described previously by Garrett and Hinman (5), except liver ether extracts, were determined by soxhlet instead of Goldfisch extraction. Empty body was the sum of blood, liver, viscera, and carcass contributions. Total body was the sum of empty body and ingesta. Sums of all body compartment weights were in all cases within .2 kg of live weight observed at beginning of D$_2$O injection.

![Figure 1. Typical deuterium oxide dilution curve and example calculation of deuterium oxide space (Goat #3033).](image-url)
<table>
<thead>
<tr>
<th></th>
<th>Total body</th>
<th>Empty body</th>
<th>Blood</th>
<th>Liver</th>
<th>Viscera</th>
<th>Carcass</th>
<th>Ingesta</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>X</td>
<td>SD</td>
<td>X</td>
<td>SD</td>
<td>X</td>
<td>SD</td>
<td>X</td>
</tr>
<tr>
<td>Water</td>
<td>31.8</td>
<td>5.3</td>
<td>27.0</td>
<td>4.8</td>
<td>2.065</td>
<td>.384</td>
<td>0.703</td>
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<tr>
<td>Dry matter</td>
<td>58.3</td>
<td>4.9</td>
<td>55.5</td>
<td>4.9</td>
<td>81.9</td>
<td>3.3</td>
<td>68.6</td>
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<tr>
<td>% Wet weight</td>
<td>41.7</td>
<td>4.9</td>
<td>44.5</td>
<td>4.9</td>
<td>18.1</td>
<td>3.3</td>
<td>31.4</td>
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<tr>
<td>Fat</td>
<td>12.101</td>
<td>5.167</td>
<td>.002</td>
<td>.001</td>
<td>.026</td>
<td>.018</td>
<td>5.218</td>
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<tr>
<td>% Dry weight</td>
<td>52.45</td>
<td>9.15</td>
<td>.54</td>
<td>.14</td>
<td>7.80</td>
<td>5.01</td>
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<tr>
<td>FFDM</td>
<td>10.07</td>
<td>1.53</td>
<td>.449</td>
<td>.100</td>
<td>.298</td>
<td>.068</td>
<td>1.171</td>
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<tr>
<td>% FFDM</td>
<td>47.55</td>
<td>9.15</td>
<td>99.46</td>
<td>.14</td>
<td>92.20</td>
<td>5.01</td>
<td>2.079</td>
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<td>Ash</td>
<td>1.972</td>
<td>.350</td>
<td>.021</td>
<td>.005</td>
<td>.017</td>
<td>.005</td>
<td>.101</td>
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<tr>
<td>% FFDM</td>
<td>19.59</td>
<td>1.65</td>
<td>4.78</td>
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<td>5.90</td>
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<td>FAFDM</td>
<td>8.098</td>
<td>1.233</td>
<td>.428</td>
<td>.095</td>
<td>.281</td>
<td>.068</td>
<td>1.071</td>
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<tr>
<td>% FAFDM</td>
<td>80.41</td>
<td>1.65</td>
<td>95.22</td>
<td>.36</td>
<td>94.10</td>
<td>2.20</td>
<td>91.66</td>
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<tr>
<td>Nitrogen × 6.25 kg</td>
<td>7.889</td>
<td>1.117</td>
<td>.431</td>
<td>.095</td>
<td>.221</td>
<td>.052</td>
<td>.964</td>
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<tr>
<td>% FFDM</td>
<td>78.46</td>
<td>1.36</td>
<td>96.25</td>
<td>.87</td>
<td>74.38</td>
<td>4.83</td>
<td>82.50</td>
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<tr>
<td>Residuals</td>
<td>209</td>
<td>.194</td>
<td>.004</td>
<td>.003</td>
<td>.06</td>
<td>.023</td>
<td>.107</td>
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<tr>
<td>Total mass, kg</td>
<td>55.2</td>
<td>11.3</td>
<td>49.3</td>
<td>10.6</td>
<td>2.517</td>
<td>.434</td>
<td>1.207</td>
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</table>

1 n = 15.
2 FFDM = Fat-free dry matter, FAFDM = fat and ash-free dry matter.
The following equations predict the various goat body components from TBWT and D20SPACE: 

\[ [D_2O]_{t_0} = 10 \] 
(\text{Y intercept of log } [D_2O]/\text{time regression from 24 to 96 h after injection, and } D20SPACE(kg) = D_2O \text{ dose (g)/}[D_2O]_{t_0} \text{ (ppm)} × 1000.

- **Empty body weight** = .932 TBWT − 2.13
  - \( r = .996 \)
  - \( S_y \cdot x = .896 \)
  - \( n = 15 \)

- **Empty body water** = 1.465 D20SPACE
  - \( r = .959 \)
  - \( S_y \cdot x = .043 \)
  - \( n = 15 \)

- **Empty body fat** = .708 TBWT − .621 D20SPACE− 6.17
  - \( r = .951 \)
  - \( S_y \cdot x = 1.721 \)
  - \( n = 15 \)

- **Empty body N** = .00702 TBWT + .0160 D20SPACE + .341
  - \( r = .948 \)
  - \( S_y \cdot x = .062 \)
  - \( n = 15 \)

- **Empty body ash** = .0172 TBWT + .0089 D20SPACE + .727
  - \( r = .696 \)
  - \( S_y \cdot x = .271 \)
  - \( n = 15 \)

- **Empty body dry matter** = .774 TBWT − .500 D20SPACE − 3.79
  - \( r = .966 \)
  - \( S_y \cdot x = 1.791 \)
  - \( n = 15 \)

Most previous workers have used D20SPACE as a fraction of TBWT to predict chemical composition. Odwongo et al. (6) used equations that predicted the mass of chemical components from the mass of D20SPACE. These latter workers linked D2O to total body water and linked water turnover to gut contents. Then total body water and gut contents were related both to a statistic called predicted empty body, and finally, fat, protein, and ash were related to this latter statistic. Although each of these intermediate relationships may have had higher regression coefficients \((r)\) than the equations presented here, the latter prediction equations are simpler to use than a series of linked equations and the associated \( r \) indicate the actual quality of the resulting predictions in a straightforward manner. The TBWT and D20SPACE make good linear predictions of all components except ash. With the diet and goats used in this trial, TBWT alone was an excellent predictor of empty body weight. This equation may not be as useful if diets of very different bulk density, wetting rates, or particle sizes were compared. Odwongo et al. (6) predicted gut water from water turnover as estimated from D₂O dilution. The relationship between gut size and water turnover undoubtedly applies to goats as it does to cattle. The fact that no such relationship was observed here \((r<.3)\) was probably due both to the narrower range of associated body weights (38 to 70 kg) we observed relative to the range included in Odwongo’s study (90 to 562 kg) and to the varying amount of amniotic fluid present in pregnant animals. Byers et al. (3) reported predictions of gut water by “peeling” out components of the early D₂O dilution curve to create multiple pool models. Later work (1) indicates that such procedures do not always improve estimates of body composition. In the present study there were no significant relationships between putative D₂O pools and gut fill.

Five of the six prediction equations represent useful tools for nutritionists utilizing dairy goats. A few cautions are in order, however. First, any accelerations in water turnover during the 4-d sampling would bias the estimated D₂O space, since the slope and intercept of the D₂O dilution curve would change. Second, these equations were developed with only 15 experimental units. More body composition data from animals of similar weight should increase the precision of these equations.

**ACKNOWLEDGMENTS**

The authors thank D. Sehnert and K. Hays for slaughtering and dissecting the goats, M. Altschul for her excellent care, and J. M. Chow, N. Hinman, D. Barnes, and R. Sainz for help in dissecting and grinding the bodies.
REFERENCES