Further Modifications to the Mobile Nylon Bag Technique to Determine Nutrient Digestibility for Swine

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ABSTRACT : Previous studies conducted with swine have reported that the mobile nylon bag technique (MNBT) does not always accurately predict in vivo nutrient digestibilities. Therefore, in this study, the MNBT was modified so that nutrient digestibilities would more closely resemble those from conventional (Con) digestibility studies obtained using the indicator method. A total of 19 feeds were tested including five cereal grains, five legumes, three high protein sources and six mixed diets. The principle changes to the MNBT included the use of a fecal collection harness which minimized the number of bags lost. In addition, previous protocols involved pooling of bags within pig while in the present experiment all bags were analyzed separately to increase the precision of the test. Finally, chemical analyses were done using the entire nylon bag plus residue rather than opening the bags and scraping out the contents. With the exception of the barley sample ($p=0.01$), dry matter digestibility (DMD) coefficients obtained with the MNBT were not significantly different from those obtained with the indicator method. The linear regression equation relating the MNBT to the indicator method was Con DMD=-0.77+1.02 MNBT DMD ($r^2=0.93$; $p<0.0001$). There was no significant ($p>0.05$) difference in gross energy digestibility (GED) coefficients determined using the MNBT or the indicator method for any of the 19 feeds. The regression line equation relating the MNBT to the indicator method was Con GED=-5.68+1.06 MNBT GED ($r^2=0.94$; $p<0.0001$). The MNBT was less effective in predicting in vivo crude protein digestibility (CPD) than it was in predicting dry matter and energy digestibility. Differences greater than five percentage units were observed for two of the legumes, Kabuli chickpeas ($p=0.02$) and the extruded pea-canola seed mixture ($p=0.01$) as well as for three of the mixed diets including the unheated hulled barley-based diet ($p=0.01$), the unheated hulless-barley based diet ($p=0.08$) and the barley-soybean meal based diet ($p=0.008$). The regression equation relating the MNBT to the indicator method was Con CPD=5.75 + 0.90 MNBT CPD ($r^2=0.76$; $p<0.0001$). This study indicates that the modified MNBT can be used for the rapid determination of dry matter and energy digestibility in a wide variety of ingredients. For the measurement of crude protein digestibility, the technique produces results similar to conventional digestibility studies for cereal grains and high protein feeds but tends to overestimate protein digestibility for legumes and mixed diets. *(Asian-Aust. J. Anim. Sci. 2001. Vol 14, No. 8 : 1149-1156)*

Key Words : Nylon Bag, Pigs, Digestibility, Protein, Energy, Cannula

INTRODUCTION

The determination of nutrient digestibility for swine typically involves either the total collection of feces (Schneider and Flatt, 1975) or the use of a digestibility marker (Young et al., 1991). Both of these techniques are time consuming and expensive and usually require a large quantity of feed (Sauer et al., 1989; de Lange et al., 1991; Viljoen et al., 1997). Some of these problems can be overcome by using the mobile nylon bag technique (MNBT) developed by Sauer et al. (1983). In this method, small samples of finely ground feed are sewn into nylon bags and placed into a small beaker containing hydrochloric acid and pepsin to simulate gastric digestion. This simmulation is necessary because nylon bags cannot pass the pyloric sphincter. After a short incubation period, the nylon bags are removed from the beaker and inserted into the digestive tract of a pig by means of a duodenal cannula. The bags travel through the digestive tract and are eventually recovered in the feces. The amount of material remaining in the nylon bag, after passage through the tract can be used to calculate total tract apparent nutrient digestibility.

Although the MNBT has produced digestibility coefficients for crude protein similar to conventional digestibility studies for high protein feeds (Sauer et al., 1983; Cherian et al., 1988; Cherian et al., 1989) and for dry matter and energy digestibility with barley (Sauer et al., 1984), other studies have reported that the technique did not accurately predict in vivo nutrient digestibilities when used for mixed feeds (Taverner and Campbell, 1985; Leterme and Thewis, 1990) and cereal grains (Graham et al., 1985; Sauer et al., 1989; de Lange et al., 1991). Therefore, this study was conducted with the aim of modifying the MNBT so that digestibility coefficients obtained with the MNBT would more closely predict those obtained from conventional digestibility studies.

MATERIALS AND METHODS

Surgical procedures

Simple T-cannulae were inserted into the duodenum of

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six barrows (Camborough Line 15, Pig Improvement Canada Ltd, Acme Alberta; 43.5±2.3 kg initial weight) following the surgical procedures described by Li et al. (1994) with some modifications. The rigid T-cannulae (24 mm i.d.×65 mm length) were fabricated from Delrin nylon rod (Johnston Industrial Plastics, Edmonton, Alberta) according to the specifications outlined by McBride et al. (1983).

The barrows were fasted for 12 h prior to surgery, but water was freely accessible. A long-acting antibiotic (Liquamycin, 0.5 mL, Rogar/STB Inc., London, Ontario) was administered intramuscularly 8 h before surgery. The pigs were brought under general anaesthesia using a mixture of oxygen (500 to 1,000 mL/min) and halothane (0.5 to 2.0%). An incision of approximately 7 cm in length was made on the right side of the pig parallel and caudal to the last rib. The duodenum was identified and a site approximately 5 to 10 cm posterior to the pyloric sphincter was chosen for insertion of the cannulae. An incision was made between two parallel sutures using a No. 25 scalpel blade and the flanges of the cannula were inserted into the lumen of the intestine through the incision. The purse-string suture was tightened and a second purse-string suture was placed around the base of the cannula approximately 2 mm below the original suture to further secure the cannula.

A fistula was created between the two last ribs by surgically removing a small piece of skin and penetrating the muscle layers and peritoneum using finger manipulation and a pair of Rochester Pean Forceps. The barrel of the cannula was then pulled through the fistula. Terramycin (0.5 mL) was administered into the abdominal cavity and the incision was closed by suturing the peritoneum as well as the inner and outer muscle layers using 2-0 catgut. The skin was sutured with 2-0 silk. A retaining ring was threaded down the barrel of the cannula and tightened to the skin. An analgesic (Butorphenol Tartate, 0.1 mg/kg bodyweight) was administered intra-muscularly immediately after surgery and again 24 h later.

Following surgery, the pigs were placed in metabolic crates and allowed a 2-week recuperation period to regain their normal appetite. Pigs received about 150 g of feed the day following surgery. The amount gradually increased to 1.5 kg feed per day. The skin sutures were removed 10 d after surgery. The tightness of the retaining ring was adjusted as the pigs grew.

Preparation of nylon bags

Nylon bags (25×40 mm) were prepared from monofilament nylon cloth (Sefar Canada Inc., Scarborough, Ontario) with a pore size of 48 um. The bags were sealed on three sides using heat (Sealboy, Packaging Aids Corporation, San Rafael, California). One gram of feed, ground through a 1.0 mm mesh screen, was placed in the bag and the remaining side of the bag was then also heat-sealed.

The bags were grouped in blocks of 12 and placed in a 1,000 mL beaker containing 500 mL of a solution made up of deionized water, 0.01 N HCl (pH 2.0) and 1 g of purified activated pepsin powder (56 Sigma Units/mg; Sigma-Aldrich Canada Ltd, Oakville, Ontario). The beaker was then placed into a shaking water bath (65 oscillations/min) and incubated for 4 h at 37°C. After incubation, the bags were removed from the beaker, washed with deionized water and frozen in small plastic bags until required. Most of the predigestion factors (i.e. pH, duration of predigestion, pore size, bag shape) were chosen because they had been shown in previous work to produce results most similar to those obtained with conventional digestibility studies (Cherian et al., 1988, 1989). A larger sample size (1 g vs 0.5 g) was chosen to ensure sufficient residue to conduct needed chemical analyses.

Determination of nutrient digestibility using the MNBT

The barrows (average weight 45.5±2.4 kg at initiation of study) were individually housed in 135×65 cm stainless steel metabolic crates. Initially, they received 750 g of a grower diet (15.9% crude protein and 12.1 MJ/kg DE) containing 70.25% barley, 26.5% canola meal and 3.25% vitamin-mineral premix during each of two daily feedings (09:30 and 16:30 h). The daily ration (processed using 4 mm mesh screen) was increased as the pigs grew but remained at 3% of body weight. The stainless steel feeder was filled with water so that water was available at all times except during feeding.

Prior to insertion, nylon bags were removed from the freezer and thawed for 5-min in a 37°C waterbath. Eight bags were administered to each pig daily. The bags were inserted into the duodenal cannula during feeding time with four bags being inserted in the morning and four bags being inserted during the afternoon meal. With each feeding, two bags were introduced 15 minutes apart (i.e. two bags at the initiation of feeding and a further two bags 15 minutes later). A total of 19 feeds were tested including five cereal grains (barley, oats, wheat and two samples of corn), five legumes (Desi chickpeas, Kabuli chickpeas, green peas, feed peas and a blend of extruded peas and whole canola seed marketed under the trade name Extrapro by Oleet Processing Ltd of Regina, Saskatchewan), three high protein sources (canola meal, soybean meal and an extruded spent hen:soybean meal blend marketed under the trade name Avipro by Oleet Processing Ltd of Regina, Saskatchewan) and six mixed diets (four diets based on hulled or hulless barley either micronized or untreated, a hulled barley-canola meal diet supplemented with Vegpro enzyme marketed by Alltech Ltd of Nicholasville, Kentucky and a second hulled barley-soybean diet). The mixed diets had all been used in experiments conducted previously at the University of Saskatchewan. The chemical composition of the test feeds as well as the ingredient composition of the mixed diets are presented in tables 1 and 2.

Only five of the barrows were used during this trial with one barrow acting as a spare. Twenty nylon bags were prepared for each feed (10 bags for protein and 10 bags for dry matter and energy) with four bags being inserted into the duodenum of each of the five barrows. A total of 380 bags were inserted over a ten-day period.

Table 1. Chemical composition (% as fed) of ingredients used to compare the mobile nylon bag technique and indicator method for digestibility measurements

	Moisture	Crude protein	Gross energy (kcal/kg)	Acid detergent fiber	Ether extract	Ash
Cereal grains						
Barley	12.0	10.8	3,988	7.9	1.7	2.5
Corn#1	13.6	8.0	3,990	3.1	3.7	1.3
Corn#2	10.9	8.9	4,021	4.7	3.9	2.8
Oats	9.8	10.9	4,272	13.6	5.0	2.8
Wheat	12.2	13.1	3,994	3.5	1.6	2.0
Legumes						
Desi chickpeas	8.4	20.1	3,952	8.8	1.8	3.3
Kabuli chickpeas	8.5	19.5	4,221	11.0	9.3	4.0
Green peas	10.6	19.3	4,244	5.8	7.3	4.3
Feed peas	9.5	20.8	4,002	7.4	1.7	3.7
Extruded peas+canola seed	6.5	19.6	5,100	9.5	19.8	4.2
Protein supplements						
Canola meal	12.8	34.6	4,388	19.1	3.2	7.1
Soybean meal	12.3	45.8	4,356	4.8	1.3	6.7
Extruded spent hen +soybean meal	6.2	44.2	5,039	5.8	12.6	6.4

Table 2. Formulation and chemical composition of mixed diets fed to compare digestibilities determined with the mobile nylon bag technique and indicator methods

	Control hulled barley	Micronized hulled barley	Control hulless barley	Micronized hulless barley	Barley+canola meal	Barley+ soybean meal
Diet formulation (% as fed)						
Hulled barley	76.40	76.40	-	-	72.50	77.38
Hulless barley	-	-	81.80	81.80	-	-
Soybean meal	18.85	18.85	13.45	13.45	-	17.65
Canola meal	-	-	-	-	22.40	-
Tallow	1.00	1.00	1.00	1.00	1.00	1.65
Dicalcium phosphate	1.50	1.50	1.50	1.50	1.50	1.56
Limestone	1.50	1.50	1.50	1.50	1.50	1.01
Salt	0.50	0.50	0.50	0.50	0.50	0.50
Vitamin-mineral premix[1]	0.25	0.25	0.25	0.25	0.50	0.25
Enzyme	-	-	-	-	0.10	-
Chemical composition (% as fed)						
Moisture	13.2	10.8	12.5	10.8	12.3	12.0
Crude protein	15.9	16.1	15.8	16.1	15.9	16.1
Ash	6.6	6.4	6.7	5.7	5.9	5.0
Ether extract	2.9	3.2	3.5	3.3	3.0	3.4
Acid detergent fibre	5.5	6.3	3.0	3.6	10.5	7.4
Gross energy (kcal/kg)	3,848	3,862	3,786	3,834	3,834	3,877

[1] Supplied per kilogram of diet: 8,250 IU vitamin A; 825 IU vitamin D_3; 40 IU vitamin E; 4 mg vitamin K; 1 mg thiamin; 5 mg riboflavin; 35 mg niacin; 15 mg pantothenic acid; 2 mg folic acid; 12.5 ug vitamin B_{12}; 0.2 mg biotin; 80 mg iron; 25 mg manganese; 100 mg zinc; 50 mg Cu; 0.5 mg I; 0.1 mg selenium.

A leather fecal collection harness (Bill's Custom Leather Crafting, Saskatoon) was glued around the anus of the pigs using Skin-Bond Cement (Smith + Nephew, Largo, Florida). Details regarding the collection system used were published previously by van Kleef et al. (1992). Plastic bags (4.5 kg polyethylene bags; UniSource Canada Ltd, Saskatoon) were clipped into the leather harness. The collection bags were taken off immediately after feeding (09:30 and 16:30 h) as well as once each evening (21:00 h) and a search made to obtain any nylon bags excreted. Most of the nylon bags were excreted within 24±4 h of insertion. Nylon bags were carefully isolated from feces and any feces sticking to the bag were scrapped off with a dry paper towel. The bags were not washed. All nylon bags were then frozen (-20°C) until needed for chemical analysis. The search for nylon bags was terminated 72 h after the insertion of the last nylon bag.

Determination of nutrient digestibility using the indicator method

The conventional digestibility studies were conducted in three batches using pigs over the weight range of 37 to 73 kg using the same 19 feeds as for the MNBT. Previous studies using pigs over a similar weight range have shown little effect of weight on the apparent digestibility of protein and energy (i.e. Fernandez and Jorgensen, 1986).

Total tract digestibility coefficients for dry matter, crude protein and gross energy were determined using 4 to 6 pigs per treatment. The actual number of pigs used for a given feedstuff is shown in table 3. Pigs were housed in groups of four in 2.7×3.6 m concrete floored pens. The pens were equipped with four individual feeders and each pig was allowed access to its own individual feeder for 30-min twice daily (07:00 h and 15:00 h). Water was available *ad libitum*.

For the majority of ingredients, the test ingredient was mixed with a vitamin-mineral premix and 0.5% chromic oxide (Anachemia Canada Inc., Montreal, Quebec) as a digestibility indicator. For the high protein sources (canola meal, soybean meal and extruded spent hen:soybean meal), the test ingredient was diluted 50:50 with corn starch. To obtain the digestibility estimates on the complete diets, the complete diets as shown in table 2 were also mixed with 0.5% chromic oxide. All of the conventional digestibility estimates were obtained with diets fed in meal form.

The marked feed was provided for a seven day

Table 3. Comparison of digestibility coefficients determined using the mobile nylon bag technique (MNBT) and the indicator method[1]

	Dry matter			Gross energy			Crude protein		
	Indicator	MNBT	SEM[2]	Indicator	MNBT	SEM	Indicator	MNBT	SEM
Cereal grains									
Barley (6)[3]	75.5[a]	73.6[b]	0.46	75.0	74.3	0.59	71.6	73.0	1.72
Corn#1 (6)	80.0	82.4	0.83	79.5	82.6	0.83	68.9	70.0	1.24
Corn#2 (6)	83.9	81.9	1.24	83.0	82.5	1.30	72.7	72.8	2.05
Oats (6)	59.4	59.8	1.44	61.5	62.9	1.54	74.9	72.0	1.51
Wheat (6)	84.2	85.3	1.58	83.6	85.3	1.71	81.0	83.7	2.23
Legumes									
Desi chickpeas (6)	79.5	75.8	1.45	78.2	77.6	1.65	75.2	78.9	2.44
Kabuli chickpeas (6)	83.3	82.0	1.26	80.9	81.9	1.27	76.4[a]	85.6[b]	2.09
Green peas (6)	84.8	82.3	1.54	83.4	83.3	1.44	83.2	84.2	2.15
Feed peas (5)	88.5	84.1	1.13	86.9	85.3	1.11	83.9	85.3	1.34
Extruded peas +canola seed (6)	82.0	79.5	1.88	83.4	80.8	1.95	77.9[a]	83.3[b]	1.32
Protein supplements									
Canola meal (6)	78.9	76.4	2.29	78.9	77.1	2.24	77.3	78.1	1.77
Soybean meal (6)	90.5	89.9	1.41	90.4	80.2	1.62	90.7	89.2	1.67
Spent hen+soybean meal (6)	89.8	88.9	1.75	89.9	88.9	1.74	85.2	86.8	1.52
Mixed diets									
Control hulled barly (4)	76.9	75.2	2.00	75.5	76.6	2.17	73.7[a]	80.5[b]	1.46
Micronized hulled barley (4)	76.4	77.4	1.03	76.6	78.4	1.11	73.5	75.9	2.15
Control hulless barley (4)	75.8	76.2	0.16	73.2	74.7	1.43	60.8[a]	70.2[b]	3.16
Micronized hulless barley (4)	80.1	81.3	1.40	79.0	81.8	1.70	72.8	67.9	3.11
Barley+canola meal (4)	67.7	68.8	1.48	67.9	70.2	1.62	62.6	64.8	2.44
Barley+soybean meal (6)	75.9	73.8	1.35	73.7	74.9	1.59	75.5[a]	80.7[b]	1.28

[1] Within nutrient, means in same row followed by same or no letter do not differ (p>0.05).

[2] Standard error of the mean. [3] Value in parenthesis indicates number of pigs used for conventional digestibility determination.

acclimatization period, followed by a three day fecal collection. Fecal collections were made by bringing animals into a clean room immediately after feeding and recovering freshly voided feces. Feces were collected twice daily and all six collections from an individual pig were pooled, mixed and subsampled. The fecal samples were frozen (-20°C) for storage. Prior to analysis, the fecal samples were thawed, then dried in a forced air oven dryer at 66°C for 60 h, followed by fine grinding (0.5 mm screen).

Chemical analysis and nutrient digestibility calculations

Analysis for dry matter and crude protein in feed and feces as well as acid detergent fiber, ash, and ether extract in the feed ingredients were conducted according to the methods of the AOAC (1980). A Parr Adiabatic Bomb Calorimeter (Model 1200, Parr Instrument Company, Moline, Il) was used to determine gross energy content of feeds and feces while chromic oxide was determined according to the method of Fenton and Fenton (1979). Digestibility coefficients for dry matter, crude protein and gross energy were calculated using the equations for the indicator method described by Schneider and Flatt (1975).

In order to measure dry matter digestibility using the mobile nylon bag technique, frozen nylon bags and residues were freeze-dried for 48 h in a Lyph-Lock 12 Freeze Dry System (Labconco, Kansas City, MO). Dry matter digestibility was calculated by subtracting the dried weight of the ingredient originally placed in the bag (sample weight corrected for moisture content of ingredient) from the dried weight of the residue after passing through the digestive tract (freeze dried residue) and expressing the difference as a percentage of the original dried sample weight.

Digestibility coefficients for gross energy were determined by tightly rolling the freeze-dried nylon bags and placing them into a calorimeter cup. The nylon bag and the residue were combusted but the energy value was corrected by subtracting the energy value of an empty nylon bag. The gross energy of the residue was subtracted from the gross energy of the original dried sample and the difference was expressed as a percentage of the gross energy of the original dried sample.

The protein content of the residue was determined by digesting nylon bags and residues in 15 ml concentrated H_2SO_4 in the presence of a Propack catalyst (Alfie Pakers, Omaha, NE) in a Tecator Block Digester (Foss-North America, Eden Prairie, MN) for 1 h at 420°C. The digested sample was then distilled in a Kjeltec 1030 Distillation System (Foss-North America) to determine ammonia concentration. The protein content of empty bags served as a blank.

Statistical analysis

A one way analysis of variance, using the General Linear Model procedure of SAS (1999), was conducted to compare digestibility coefficients obtained with the indicator method (Con) and those obtained with the MNBT. A simple linear regression of conventional nutrient digestibility and MNBT nutrient digestibility was conducted using the regression procedure of SAS (1999). The first equation (non 0 intercept) included an intercept and indicated the fit (adjusted r^2) and precision (RSD) of the MNBT to estimate conventional digestibility. The degree to which the MNBT either underestimated or overestimated nutrient digestibility (bias) was calculated as the percentage deviation of the slope from a theoretical value of 1.0 when the MNBT digestibility was regressed on conventional digestibility using a zero-intercept model (Mayer and Butler, 1993).

RESULTS AND DISCUSSION

Dry matter digestibility

Dry matter digestibility (DMD) coefficients determined using the MNBT and the indicator method (Con) are compared in table 3. For the cereal grains, barley was the only ingredient where a significant difference was obtained between the two techniques (p=0.01). However, even for barley, it should be noted that the digestibility coefficients obtained differed by only 1.9 percentage units and it is unclear whether this difference has biological significance or is merely an artifact of the statistical analysis.

Figure 1 shows the relationship between digestibility coefficients obtained with the MNBT and the indicator method. The linear regression equation relating the MNBT to the indicator method was Con DMD=-0.77+1.02 MNBT DMD (r^2=0.93; p<0.0001; SE of slope=0.06; SE of intercept=4.99). Forcing the line through the zero intercept indicated that the MNBT underestimated dry matter digestibility with a bias of 1%.

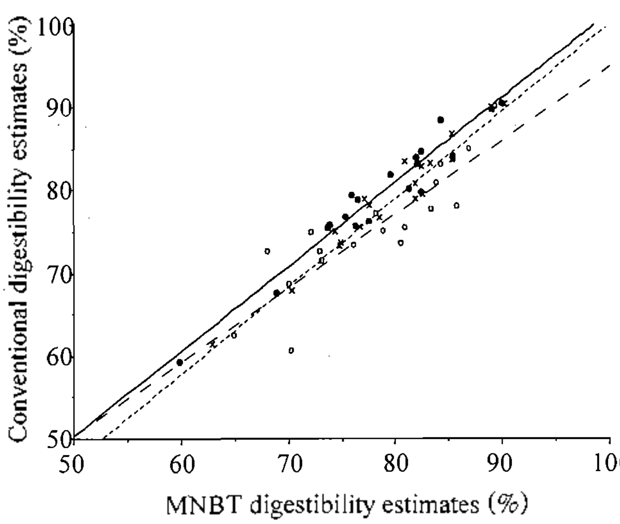
The MNBT has not been widely utilized to predict dry matter digestibility. However, the results of the present study indicate that there was excellent agreement between the modified MNBT and the indicator method in estimating dry matter digestibility coefficients over the complete range of feedstuffs tested (i.e. cereal grains, legumes, high protein feeds and mixed diets). In previous studies, Sauer et al. (1984) reported good agreement (i.e. differences of less than one percentage unit) between the MNBT and in vivo digestibility for three barley cultivars. However, Taverner and Campbell (1985) reported that the MNBT underestimated dry matter digestibility by 6.2 to 8.8 percentage units when used for mixed feeds. Similarly, Leterme and Thewis (1990) reported differences in digestibility greater than 3.5 percentage units in two mixed feeds when comparing the MNBT to in vivo digestibility.

Gross energy digestibility

Digestibility coefficients for gross energy (GED) determined using the MNBT and the indicator method are compared in table 3. The modified MNBT was very effective in predicting in vivo energy digestibility as there were no significant ($p>0.05$) differences between the techniques in digestibility coefficients for either cereal grains, legumes, high protein supplements or mixed diets.

Figure 1 shows the relationship between digestibility coefficients obtained with the MNBT and the indicator method. The regression line equation relating the MNBT to the indicator method was Con GED=-5.68+1.06 MNBT GED ($r^2=0.94$; $p<0.0001$; SE of slope=0.06; SE of intercept=4.65). Forcing the line through the zero intercept indicated that the MNBT overestimated gross energy digestibility with a bias of 1%.

The MNBT, as modified for the current study, would appear to have greater potential for use in estimating digestibility coefficients for energy than has been shown in previous studies. For example, de Lange et al. (1991) reported that the MNBT underestimated energy digestibility in cereal grains by 8 to 14 percentage units. Graham et al (1985) used the MNBT to measure organic matter digestibility and reported differences greater than 5 percentage units between the MNBT and conventional digestibility determinations for both cereal grains and legumes. In contrast, Sauer et al. (1984) reported differences of less than 1 percentage unit between the MNBT and *in vivo* digestibility for three barley cultivars.



Con DMD=-0.77+1.02 MNBT DMD $r^2=0.93$ (RSD=1.89)

Con GED=-5.68+1.06 MNBT GED $r^2=0.94$ (RSD=1.61)

Con CPD=5.75+0.90 MNBT $r^2=0.76$ (RSD=3.50)

Figure 1. Regression lines relating mobile nylon bag (MNBT) and conventional (CON) estimates for dry matter digestibility (DMD), gross energy digestibility (GED) and crude protein digestibility (CPD) across all samples

Crude protein digestibility

The MNBT was less effective in predicting in vivo crude protein digestibility (CPD) than it was in predicitng dry matter and energy digestibility (table 3). Differences greater than five percentage units were observed for Kabuli chickpeas ($p=0.02$) and the extruded pea-canola seed blend ($p=0.01$) as well as for three of the mixed diets including the unheated hulled barley-based diet ($p=0.01$), the unheated hulless-barley based diet ($p=0.08$) and the barley-soybean meal based diet ($p=0.008$). For the remaining feeds, the two techniques produced similar ($p>0.05$) digestibility coefficients.

Figure 1 shows the relationship between protein digestibility coefficients obtained with the MNBT and the indicator method. The regression line equation was Con CPD=5.75+0.90 MNBT CPD ($r^2=0.76$; $p<0.0001$; SE of slope=0.11; SE of intercept=9.05). When the regression line was forced through the zero intercept, the MNBT overestimated crude protein digestibility with a bias of 3%.

The modified MNBT protocol appeared to be effective in predicting *in vivo* protein digestibility for cereal grains with the two techniques producing similar ($p>0.05$) digestibility coefficients. As such, this is an advancement on the previous studies with the MNBT where differences of greater than 10 percentage units were reported between the MNBT and conventional studies when used to measure protein digestibility for cereal grains (Graham et al., 1985; Sauer et al., 1989).

There was also good agreement ($p>0.05$) between the modified MNBT and in vivo protein digestibility when the technique was applied to high protein sources. These results are therefore similar to those obtained by Sauer et al. (1983) following their initial protocol and the subsequent protein digestibility studies reported by Cherian et al. (1988, 1989) and Sauer et al. (1989) for high protein feedstuffs.

Unfortunately, the modified MNBT tended to over-estimate protein digestibility when applied to mixed diets. For three of the six diets tested, the modified MNBT produced different ($p<0.05$) digestibility coefficients for crude protein than did the indicator method. As such, these results are similar to those of Leterme and Thewis (1990) and Sauer et al. (1989) who also reported significant differences between the MNBT and conventional digestibility techniques in 50% of the mixed diets they tested. There are no obvious differences in the chemical analysis of these diets which would help explain why, with certain diets, the modified MNBT does not accurately predict *in vivo* crude protein digestibility.

A weakness of the modified MNBT is that it can only be used to predict total tract CDP. Ileal digestibilities are generally preferred to total tract digestibilities because they take into account the modifying effects of bacterial metabolism in the hindgut (Sauer and Ozimek, 1986). However, since the determination of ileal digestibility is relatively time consuming, feed manufacturers are often forced to rely on "book values" for the ileal digestibility of various feedstuffs when formulating feeds. In contrast, when using the MNBT, once surgery is completed, it is possible to obtain the total tract CDP of many feeds in a very short time. It may be argued that formulating a ration using a total tract CDP determined on the actual sample of feed to be consumed could be as accurate as formulating a diet using an ileal digestibility value obtained from a book.

Modifications to the MNBT

The proposed version of the MNBT involves several changes from the protocol previously proposed by Sauer et al. (1983). The first change involved the use of a collection harness which minimized the number of bags lost or damaged. Four bags were inserted during each feeding compared with two bags per meal in earlier protocols. In addition, previous protocols involved pooling of bags within pig while in this experiment all bags were analyzed separately thus increasing the number of replications and increasing the precision of the test. Perhaps the most significant change was the fact that the chemical analysis for dry matter, crude protein and energy were done using the entire nylon bag plus residue rather than opening the bags and scrapping out the contents. It was felt that this minimized the potential for errors arising from loss of residue during the transfer process. Finally, the conventional studies were conducted using the indicator method rather than total fecal collection.

IMPLICATIONS

The overall results of this study indicate that the MNBT, modified to include the use of a collection harness and individual analysis of nylon bags, can be used for the rapid determination of dry matter and energy digestibility in small samples of feeds. For the measurement of crude protein digestibility, the technique produces results similar to conventional total tract digestibility studies for cereal grains and high protein feeds but tends to overestimate protein digestibility for legumes and mixed diets.

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REFERENCES

AOAC. 1980. Official Methods of Analysis (13th Ed.) Association of Official Analytical Chemists, Arlington VA.

Cherian, G., W. C. Sauer and P. A. Thacker. 1988. Effect of predigestion factors on the apparent digestibility of protein for swine determined by the mobile nylon bag technique. J. Anim. Sci. 66:1963-1968.

Cherian. G., W. C. Sauer and P. A. Thacker. 1989. Factors affecting the apparent digestibility of protein for swine when determined by the mobile nylon bag technique. Anim. Feed Sci. Technol. 27:137-146.

de Lange, C. F. M., W. C. Sauer, L. A. den Hartog and J. Huisman. 1991. Methodological studies with the mobile nylon bag technique to determine protein and energy digestibilities in feedstuffs for pigs. Livest. Prod. Sci. 29:213-225.

Fenton, T. W. and M. Fenton. 1979. An improved procedure for the determination of chromic oxide in feed and faeces. Can. J. Anim. Sci. 59:631-634.

Fernandez, J. A. and J. N. Jorgensen. 1986. Digestibility and absorption of nutrients as affected by fibre content in the diet of the pig. Quantitative aspects. Livest. Prod. Sci. 15:53-71.

Graham, H., P. Aman, R. K. Newman and C. W. Newman. 1985. Use of a nylon-bag technique for pig feed digestibility studies. Br. J. Nutr. 54:719-726.

Leterme, P. and A. Thewis. 1990. Methodological aspects of the mobile nylon bag technique in pigs. Arch. Anim. Nutr. Berlin 40:1027-1036.

Li, S., W. C. Sauer and R. T. Hardin. 1994. Effect of dietary fibre level on amino acid digestibility in young pigs. Can. J. Anim. Sci. 74:327-333.

Mayer, D. G. and D. G. Butler. 1993. Statistical validation. Ecol. Modelling 68:21-32.

McBride, B. M., R. Berzins, L. P. Milligan and B. W. Turner. 1983. Development of a technique for gastrointestinal endoscopy of domestic ruminants. Can. J. Anim. Sci. 63:349-354.

National Academy of Sciences-National Research Council, 1998. Nutrient Requirements of Domestic Animals. No. 2. Nutrient Requirements of Swine. 10th Ed. NAS-NRC, Washington, DC.

SAS. 1999. SAS Users Guide, Version 8, SAS Institute Inc., Cary, NC.

Sauer, W. C., H. Jorgensen, and R. Berzins. 1983. Modified nylon bag technique for determining apparent digestibilities of protein in feedstuffs for pigs. Can. J. Anim. Sci. 63:233-237.

Sauer, W. C. and L. Omimek. 1986. Digestibility of amino acids in swine: Results and their practical applications. A review. Livest. Prod. Sci. 15: 367-388.

Sauer, W. C., L. A. den Hartog, J. Huisman, P. van Leeuwen, and C. F. M. de Lange. 1989. The evaluation of the mobile nylon bag technique for determining the apparent protein digestibility in a wide variety of feedstuffs for pigs. J. Anim. Sci. 67:432-440.

Sauer, W. C., L. Ozimek and L. A. den Hartog. 1984. The mobile nylon bag technique for determining dry matter and energy digestibilities in barleys for pigs. J. Anim. Sci. 59(Suppl. 1):271(Abstr.)

Scheider, B. H. and W. P. Flatt. 1975. The Evaluation of Feeds Through Digestibility Experiments. University of Georgia Press, Athens, Georgia.

Taverner, M. R. and R. G. Campbell. 1985. Evaluation of the mobile nylon bag technique for measuring the digestibility of pig feeds. In: Proc. 3rd Intern. Seminar on Digestive Physiology in the Pig (Ed. A. Just, H. Jorgensen and J. A. Fernandez). Copenhagen, Denmark. pp 385-388.

van Kleef, D. J., K. Deuring and P. van Leeuwen. 1994. A new method of faeces collection in the pig. Lab. Anim. 28:78-79.

Viljoen, J., M. N. Ras, F. K. Siebrits and J. P. Hayes. 1997. Use of the mobile nylon bag technique (MNBT) in combination with the ileo-rectal anastomosis technique (IRA) to determine amino acid digestibility in pigs. Livest. Prod. Sci. 51:109-117.

Young, L. G., A. G. Low and W. H. Close. 1991. Digestion and metabolism techniques in pigs. In: Swine Nutrition (Ed. E. R. Miller, D. E. Ullrey and A. J. Lewis). Butterworth-Heinemann, Boston, Mass. pp 623-630.