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Variation of fibre and follicle characteristics related to wool bulk over the body of Perendale ewes: Implications for measurement of wool bulk

R.M.W. SUMNER AND A.J. CRAVEN

AgResearch, Ruakura Research Centre, Private Bag 3123, Hamilton, New Zealand.

ABSTRACT

Wool samples were collected prior to shearing in two consecutive years from 8 sites over the body of six adult Perendale ewes differing in wool bulk. A skin sample was collected from the same sites in the second year. Fibre curvature and fibre diameter explained between 67 and 94% the variation in core bulk at the different sites. No measured characteristics significantly reduced the unexplained variance across all sites. Intercepts for the relationship between fibre curvature and fibre diameter with core bulk at each site were significantly different but less than the confidence limits associated with core bulk measurement. There were no significant differences in the slopes of the same relationships across the eight sites. Use of a pooled relationship to predict bulk from fibre curvature and fibre diameter is a least-cost option to describe the bulk of a fleece.

Keywords: wool bulk; site variation; fibre characteristics; follicle characteristics; Perendale.

INTRODUCTION

Wool bulk, or the ability of an assembly of fibres to fill a space, is closely related to the performance of many of the products produced from Romcross type wool. Increased wool bulk results in a fuller and more extensible yarn providing increased yarn bulk and less shrinkage in knitted products, and improved appearance retention and wearability in carpets (Sumner *et al.*, 1991). The expression of bulk is strongly associated with fibre curvature, fibre diameter and follicle curvature (Dick and Sumner, 1997; Sumner and Dick, 1997). Bulk is also strongly inherited and controlled by relatively few genes (Sumner *et al.*, 1995; Wuliji *et al.*, 1995).

Individual fleeces are variable due to within-fibre, between-fibre and between-site variation, with pronounced ventro-dorsal and anterio-posterior gradients over the body for dimensional fibre characteristics that can be measured objectively (Bigham *et al.*, 1984; Sumner and Revfeim, 1973; Young and Chapman, 1958), which are in turn, influenced by dimensional follicle characteristics. Based on these and associated studies, the midside is generally considered to be the most representative site for sampling the fleece. Consequently, measurements taken from the midside have been used extensively in selection and physiological studies of the biology of wool bulk (Sumner *et al.*, 1995; Wuliji *et al.*, 1995; Edmunds and Sumner, 1996; Dick and Sumner, 1997; Sumner and Dick, 1997; Sumner, 1999).

No published estimates are available for site variation for fibre curvature and its interrelationship with other fibre and follicle characteristics over the body. This paper reports site variation for fibre and follicle characteristics associated with the expression of bulk and their interrelationships in a group of Perendale ewes differing in wool bulk.

MATERIALS AND METHODS

Sampling

Six unmated adult Perendale ewes born at AgResearch, Whatawhata Research Centre were used. Three of the ewes were born in a line selected for increased wool bulk at hogget shearing and three were born in a line selected for decreased wool bulk (Sumner *et al.*, 1995). The ewes were maintained and handled in compliance with a protocol approved by the Ruakura Animal Ethics Committee in accordance with the code of ethical conduct for animal experimentation within AgResearch. Wool samples (approximately 40 g) were collected immediately prior to two consecutive annual shearings in September in the first year and October in the second year from eight body sites. The position of the sites, referred to as neck; wither; back; rump; shoulder; midside; britch and belly is shown in Figure 1. Individual live weights were recorded at each sampling.

Six weeks after the second shearing, two skin samples were taken from the centre of the same eight sites as the wool samples. One sample was taken by trephine (1 cm diameter) and the other by snip biopsy. Both sets of skin samples were fixed in phosphate-buffered 10% formalin.

Wool measurements

Staple length of the greasy wool sample was measured and the total number of crimps along the staple counted. Both parameters were adjusted by proportion to reflect 52 weeks' wool growth. Crimp frequency was calculated as total number of crimps along the staple divided by staple length. Each wool sample was individually washed in water and detergent. Core bulk (Standards Association of New Zealand, 1994), and mean fibre diameter, fibre diameter variation and mean fibre curvature (Edmunds, 1995) of cored sub-samples of the scoured fleece samples were measured.

Skin measurements

Skin samples taken with a trephine were embedded in wax and transverse sections (7 mm) cut in the region of the sebaceous gland before staining by the sacpic method (Nixon, 1993). The relative ratio between primary and secondary follicles (S/P ratio), and total follicle density were each measured by projection microscope and follicle density adjusted for shrinkage of each skin section. Longitudinal sections (2 mm) were cut from each of the snip biopsy samples, stained with 0.25% nile blue sulphate and scored for follicle curvature by three assessors on a scale of 1 (straight) to 7 (highly curved) (Maddocks and Jackson, 1988).

Statistical analysis

Data were analysed by analyses of variance (GENSTAT) (Lawes Agricultural Trust, 1993) fitting effects of year of sampling, site and selection line after a $\log_e$ transformation to enable variation over the body to be analysed as a ratio relative to the midside. The year-of-sampling effect was included in the error term for testing selection line and site effects. Mean values of each selection line were back-transformed for presentation. Site effects on the interrelationship between core bulk and the measured fibre and follicle characteristics were assessed by multiple regression techniques (GENSTAT) (Lawes Agricultural Trust, 1993). Combinations of measured fibre curvature and fibre diameter were used to generate predictive models for measured core bulk at each site.

RESULTS

Mean live weight of the sheep at each sampling was 61.0±3.8 kg and 67.1±4.3 kg for year 1 and 2 respectively. The overall mean and range across sheep and sites of the measured fibre and follicle characteristics are given in Table 1.

TABLE 1: Overall mean and range for each of the measured characteristics across the six sheep and eight sites.

Characteristic	Mean	Minimum	Maximum
Core bulk (cm^3/g)	27.7	22.2	35.5
Fibre diameter (mean) (mm)	39.2	31.9	45.7
Fibre diameter (SD) (mm)	7.9	6.0	10.5
Fibre curvature (˚/mm)	46.4	26.3	83.2
Staple length (mm)	128	74	169
Total crimps/staple	17.1	12.0	28.0
Crimp frequency (crimps/cm)	1.38	0.85	2.43
Total follicle density (follicles/mm^2)	10.1	3.5	17.4
S/P ratio	4.03	3.00	5.00
Follicle curvature grade	2.8	1.2	4.7

The year-of-sampling and year-of-sampling by site interactions were not significant for each of the measured characteristics. There were no significant interactions between the selection line and site effects for any characteristics (Table 2).

Ewes born in the high bulk selection line had a higher core bulk, higher fibre curvature, shorter staple length and more highly-curved follicles than ewes born in the low bulk selection line. Although the selection line by site interaction was not significant for crimp frequency, there were more crimps per centimetre in the fleeces of ewes from the high bulk line than in those of ewes from the low bulk line at all sites other than the neck, where the crimp frequency was similar. Overall, there was no significant selection line effect for crimp frequency. There was also no significant selection line effect for mean fibre diameter, fibre diameter standard deviation, total crimps per staple, total follicle density and S/P ratio.

TABLE 2: Back-transformed least square means for the selection line effect for the measured fibre and follicle characteristics.

Characteristic	Bulk selection line		LSR*	Significance
	Low	High	(%)	
Core bulk (cm^3/g)	25.6	29.6	6.1	**
Fibre diameter (mm)	40.1	38.3	5.3	NS
Fibre curvature (˚/mm)	38.6	52.9	16.2	**
Staple length (mm)	142	112	9.1	**
Total crimps/staple	16.5	17.0	17.6	NS
Crimp frequency (crimps/cm)	1.16	1.52	22.7	NS
Total follicle density (follicles/mm^2)	8.6	10.6	54.1	NS
S/P ratio	3.90	4.09	16.3	NS
Follicle curvature grade	2.2	3.3	27.5	*

* Least squares ratio. Effect significant at 5% level of significance where the % ratio of the means exceeds the quoted value.

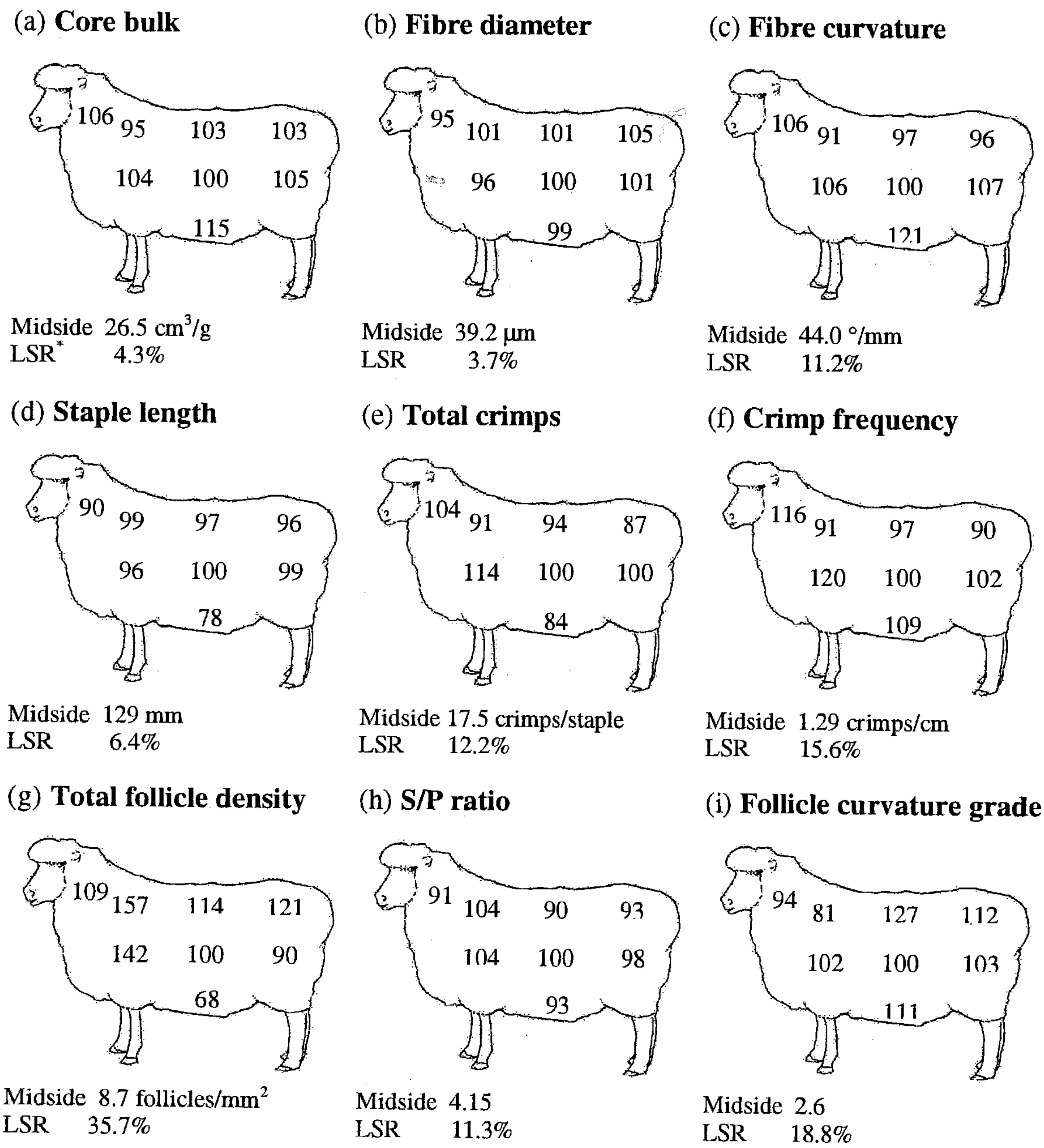
There was a highly significant site effect for all measured characteristics except fibre diameter standard deviation. The extent of the variation over the body for each of the measured characteristics, except fibre diameter standard deviation, is shown in Figure 1 as the mean for each site across all sheep expressed relative to the midside.

In general, sites on the upper and mid regions of the body did not differ significantly for most characteristics while the neck and belly tended to be different from the other sites. Wool on the belly was more bulky, with a higher fibre curvature, shorter staple length, fewer total crimps per staple and a lower wool follicle density than the body sites. The neck tended to be intermediate between the belly and the mean of other body sites for core bulk, staple length and total follicle density.

The total number of crimps imparted to the wool during the year, was highest on the shoulder. Hence, crimp frequency was also higher on the shoulder than on the three “back” sites as staple length was not significantly different over the mid and upper body. Neck wool also had a higher crimp frequency than the other body sites. Fibre and follicle characteristics tended to be more variable between sheep in the wither region than at other sites. There was also a distinct effect for the finest wool in the fleece to grow in the neck and shoulder region and the coarsest wool to grow on the rump. Likewise there were also pronounced body gradients for total follicle density over the body that were of a greater magnitude than those for fibre diameter. Follicle density was lowest on the belly, increasing in a dorso-ventral and posterio-anterior direction to be highest on the wither. With the exception of follicles in the wither region that tended to be straighter, there were no defined trends across the body for follicle curvature grade.

Multiple regression analyses showed fibre curvature and fibre diameter together explained 67%, 84%, 79%, 82%, 79%, 79%, 94% and 84% of the variation in core bulk on the neck, wither, back, rump, shoulder, midside, britch and belly. The inclusion of any of other measured characteristics did not consistently reduce the unexplained variance at all of the eight sites. Nevertheless, fibre diameter standard deviation was initially introduced into an analysis of deviance of possible factors to predict core bulk across sites (Table 3).

FIGURE 1: Trends over the body of six sheep for eight site means of measured fibre and follicle characteristics expressed relative to the midside site (100).



* Least squares ratio. Ratios different by more than the quoted value are different at the 5% level of significance.

TABLE 3: Summary of analysis of deviance testing for significance of key characteristics influencing core bulk and their interrelationship across the eight sites.

Model term	Degrees of freedom	Mean square	Significance
+ Fibre curvature	1	695.70	***
+ Fibre diameter (mean)	1	28.95	***
[Fibre diameter (SD)	1	0.22	NS
+ Site – Constants[1]	7	3.18	*
+ Site – Fibre curvature slope	7	0.94	NS
+ Site – Fibre diameter (mean) slope	7	2.27	NS
Residual	71	1.37	

[1] Selected model. Coefficients for this model are given in Table 4.

This extra measurement, which is available at no additional cost when fibre diameter is measured by either OFDA or Laserscan, has been used in previous prediction analyses (Edmunds and Sumner, 1996). While fibre curvature and fibre diameter were both highly significant in predicting core bulk, fibre diameter standard deviation was not significant and was dropped from the analysis (Table 3). Models with different slopes for fibre curvature or for fibre diameter were not significantly different from a prediction model with a single slope for each characteristic. However, a prediction model with different constants for each site explained significantly more variation in core bulk than a model with only one constant, ($P = 0.03$). Although significant, the differences between the constants at each site (Table 4) were small in biological

TABLE 4: Individual constants ± SE for the relationship between core bulk and a combination of fibre curvature and fibre diameter at each site for model selected in Table 3.

Site	Coefficient: Fibre curvature	Coefficient: Fibre diameter	Constant
Neck	+0.31 ± 0.02	+0.32 ± 0.08	+1.94 ± 3.8
Wither			+0.2 ± 3.9
Back			+1.4 ± 3.9
Rump			+1.0 ± 4.0
Shoulder			+1.3 ± 3.8
Midside			+0.8 ± 3.9
Britch			+0.7 ± 4.0
Belly			+1.5 ± 4.1
Overall	+0.31 ± 0.02	+0.29 ± 0.07	+2.1 ± 3.2

terms and within the normal confidence limits of a bulkometer when measuring core bulk (±7% of mean) (Edmunds and Sumner, 1996). Predicted core bulk values derived from a pooled relationship (Table 4) are plotted against measured core bulk in Figure 2.

DISCUSSION

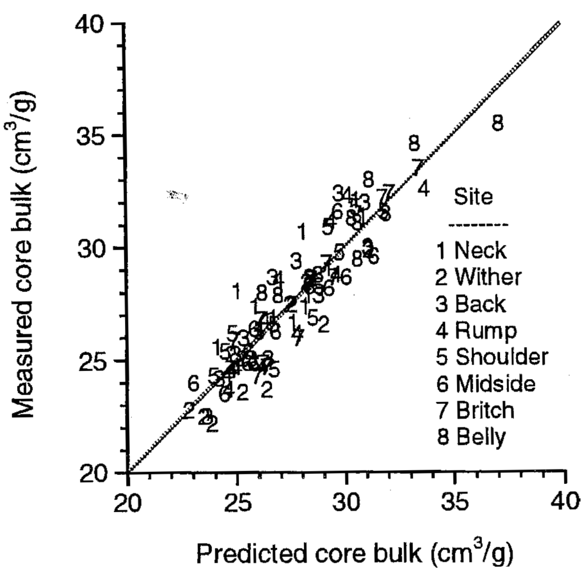
Conventional wool handling procedures employed when preparing Romcross type wool for use by commercial processors, are to separate the belly wool from the fleece. If the neck or back wool is either cotted or contains vegetable matter, and the rest of the fleece is free of vegetable matter, this wool is also removed from the fleece. Consequently, parcels of wool offered for sale contain wool grown over most of the body of sheep. Having established strong repeatable relationships between characteristics related to wool bulk in the midside region (Dick and Sumner, 1997; Sumner and Dick, 1997) it was considered important to investigate the applicability of these relationships over the fleece as a whole. Understanding these relationships would be of assistance in interpreting processing trial results as well as being important in their own right if and when wool is traded with respect to objective measurement of wool bulk at some time in the future.

The expression of fibre crimping has a complex and poorly understood, physiological basis related to fibre structure, fibre diameter, fibre length growth rate, follicular growth rate and follicle density. Follicle curvature, once established, does not change with increasing age, whereas fibre growth parameters are dynamic, although appearing to maintain some relativity to each other (Sumner and Dick, 1997). The wide range of parameters investigated in this trial was chosen to optimise the chances of explaining potential changes in relationships between fibre and wool characteristics related to wool bulk over the body of the sheep.

While few sheep were involved in this trial, the measured data were repeatable between years and within the range previously reported for Perendale ewes (Dick and Sumner, 1997; Sumner and Dick, 1997).

These results demonstrate a strong relationship between fibre curvature, fibre diameter and core bulk. It is currently considerably cheaper to measure fibre curvature and fibre diameter by OFDA or Laserscan instruments and predict core bulk, than it is to measure core bulk directly. The slope and intercepts for the relationships between fibre curvature, fibre diameter and core bulk throughout the fleece in this trial are similar This suggests that predictive assessments of core bulk could be used to compare lots of pressed unprocessed wool, as well as to rank individual sheep for wool bulk.

FIGURE 2: Predicted core bulk using the overall relationship given in Table 4 versus measured core bulk over the eight sites measured on six sheep. Line of perfect agreement is shown.



Standard test methods have been published for measuring fibre diameter using an OFDA (IWTO, 1998) or Laserscan (IWTO, 1995), and for measuring core bulk (Standards Association of New Zealand, 1994). These methods are regularly used by International Accreditation New Zealand (IANZ) accredited test houses within New Zealand. There is no published standard test method for fibre curvature. Consequently, while the relationships between characteristics at different sites were not different in practical terms, the intercept and the coefficients relating to fibre curvature may differ between data measured by different test houses due to procedural differences.

Ignoring belly wool, which is traded as a separate type, relationships between wool characteristics on the neck region and other sites were weaker than relationships between other sites. In a Romcross type fleece, the amount of wool that is traditionally referred to as "neck wool" is generally less than 3% (Henderson, 1965). As such, any aberrant relationships are unlikely to influence the estimate of core bulk of the parcel of wool as a whole.

These data have also highlighted that wool growing adjacent to the back bone tends to be inconsistent with ventro-dorsal and anterio-posterior gradients across adjacent sites for characteristics associated with crimping and follicle curvature. This may be due to the effects of weathering damaging the fibre and possibly affecting the skin itself. Follicles at the wither were straighter than expected relative to the adjoining sites, resulting in both a lower fibre curvature and a lower core bulk at that site. As with neck wool, the overall effect on the line of fleece wool caused by including small amounts of "off-type" wool grown on the wither would have an insignificant effect on the overall processing and end-product performance of the line of wool.

The higher mean S/P ratio at the wither, which has also been observed in another trial (Craven *et al.*, unpublished), may be due to an inherent difficulty with primary follicle identification at this site. With the possible exception of the wither, the S/P ratio did not differ over the body of this group of sheep. Consequently, the individual density of P and S follicles can be expected to follow a similar "across the body" trend to total follicle density, with the possible exception of the wither.

Fibre growth at different sites over the body is under genetic control and, in the case of the neck and back, may also be influenced by management and other environmental factors/procedures. Nevertheless, the compressional properties of the harvested fibre have been shown in this trial to be principally dependent on the physical dimensions of the fibre mass rather than a direct effect associated with the site on the body. These results indicate an opportunity to reduce current testing costs when preparing and marketing high-bulk wools according to objective specifications by selecting sheep for breeding and assessing fleeces at one site in the knowledge that similar trends are present within the fleece as a whole.

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