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Variation of wool characteristics across the body of New Zealand Wiltshire sheep

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ABSTRACT

Variations in wool quality within a sheep arise from inherent differences between sites across the body and between fibres within a site, as well as variations along individual fibres that result from nutritional, reproductive and seasonal influences. The Wiltshire sheep is a shedding breed in which there is renewed interest due to the relative values of meat and wool, and the costs of wool production. Staple length, fibre diameter, fibre diameter standard deviation, and medullation were measured on wool grown at seventeen sites across the body of two-tooth Wiltshire rams undergoing a photoperiod-induced wool growth cycle. Staple length was longest on the shoulder (41 ± 2.5 mm) and shortest on the belly (14 ± 1.2 mm). There was an inverse correlation between staple length and fibre diameter with the finest fibres on the shoulder and coarsest on the hip ($R^2 = -0.7$, $P < 0.001$). This gradient of increasing fibre diameter was associated with increased variation within-staples ($R^2 = -0.8$, $P < 0.001$). Fibre medullation increased from the shoulder to the hip. Short coarse fibres on the front and back legs, along with facial hairs highlight differences in major regional skin domains that are established *in utero*. Although midside samples were representative for each fleece they did not portray the anterior/posterior and dorsal/ventral gradients observed in all characteristics studied. Understanding the within-fleece variation in wool characteristics is a requirement for producing sheep with more desirable fleece distribution patterns.

Keywords: Wiltshire sheep; wool; topobiology; staple length; fibre diameter; medullation.

INTRODUCTION

Fibre structural characteristics provide the basis for payment to wool producers with the largest premium associated with a uniform fine fibre diameter. Large variations in fibre length, diameter and medullation are detrimental to the processing of wool into a range of products (Stobart *et al.*, 1986) and detract from the commercial value of the fibre. These variations in fibre quality arise from differences

(1) between sheep,

(2) between sites across the body of the sheep,

(3) between fibres within a site, and

(4) along individual fibres.

Within-fibre variations can arise from changes in mitotic rate of the follicle bulb and are largely due to nutritional, reproductive or seasonal factors (Dunlop & McMahon, 1974; Olivier *et al.*, 1993; Stobart *et al.*, 1986) and can be managed by farm practices to some extent. In contrast, variations between fibres occur temporally and spatially across the body and some of this variation may arise due to differences between follicles that are determined by developmental processes *in utero*. However, the mechanisms that regulate these follicle-forming processes are still unclear.

New Zealand (NZ) Wiltshire sheep have previously been farmed for the production of prime lambs due to their easy-care, high fecundity, good mothering ability, and rapid growth of lambs. In recent years, there is renewed interest in the breed due to its ability to shed its fleece, thus saving the grower the costs associated with crutching and shearing. Furthermore, low quality wool from body regions such as the belly and breech provide marginal profits due to the relative values of meat and wool, and the costs of production (Scobie *et al.*, 2006). When a wool follicle sheds its fibre, mitotic activity in the bulb ceases and follicles pass through the regressive (catagen) and resting (telogen) phases of the hair growth cycle. Reactivation of the follicle (proanagen) results in the growth of a new fibre and occurs naturally through the spring and summer, resulting in a biannual pattern of wool growth (Parry *et al.*, 1991; Ryder & Stephenson, 1968; Slee, 1965). Fleece shedding occurs as the old wool fibres are released from their follicles and occurs concurrently with the growth of new fibres.

The highly seasonal pattern of wool growth of the NZ Wiltshire has been exploited to study the physiological mechanisms underlying wool follicle growth cycles (Nixon *et al.*, 2002; Parry *et al.*, 1995; Pearson *et al.*, 1996; Rufaut *et al.*, 1999). The experimental suppression of pituitary prolactin secretion during spring, followed by an abrupt prolactin surge at termination of the inhibition in summer, induces a synchronised follicle growth

cycle (Craven *et al.*, 1995). The subsequent follicular events resemble those occurring spontaneously in untreated animals during spring (Ryder & Stephenson, 1968; Slee, 1965).

Although most other breeds do not undergo seasonal follicle cycling, they nevertheless exhibit marked variations in fibre growth rate (Bigham *et al.*, 1978). The New Zealand Wiltshire therefore represents one end of a continuum of follicle behaviour that extends to other breeds.

Follicle cycling in the Wiltshire also varies topographically, with waves of differential growth spreading over the body of the sheep (Slee, 1965). Thus it is important to understand the inherent variability in fleece characteristics over the body of the New Zealand Wiltshire because these sheep also represent an extreme-case model for topographic variation in fleece properties. Although generally described as having an average mean fibre diameter in the region of 30 to 33 μm and a staple length in the region of 25 to 50 mm (Wools of New Zealand, 1994), little is known about the characteristics of the NZ Wiltshire fleece and no information has been available on the variations of wool across their body. In this study we describe these traits of the wool and hair ranging across the NZ Wilshire body including the face, legs and breech.

MATERIALS AND METHODS

Animals and sampling

On 13th March 2006 wool was sampled from 17 body sites from the right side of 17 two-tooth NZ Wiltshire rams. This harvested wool represented an entire growth cycle commencing from the natural follicle reactivation (proanagen) in early spring (September 2005) until an artificially synchronised "post long-day release" follicle shutdown (catagen) on the 10th January 2006, as described previously (Craven *et al.*, 1995). All animal experimental procedures were conducted under the supervision of the AgResearch Ruakura Animal Ethics Committee.

The wool was clipped close to the skin from a 5 x 5 cm area using Oster animal clippers fitted with a number 40 blade. Hence, wool harvesting occurred during the quiescent (telogen) period of the follicles prior to any wool shedding or renewed fibre regrowth. The sites of wool sampling are shown in Figure 1. In addition to 14 sites across the fleece-bearing regions (sites 2-14), samples were taken from the face, (approximately 5 cm above the nostrils), belly (ventral midline), fore- and hind-legs (approximately 7 cm above the hoof) and breech (5 cm laterally from the anus). Thus, the sampling pattern spans regions of skin from differing embryonic origins.

The length of wool staples from each site was measured with callipers. Mean fibre diameter, fibre diameter standard deviation (FDSD) and medullation of 2000 fibres from each sample were then measured by OFDA 100 (Fibre Measurement Services, Mosgiel).

Statistical analyses

Differences between animals and sites were assessed by analysis of variance. Overall mean values and SEM are reported. Trends across and down the body sites were tested by calculating the rank correlation for each animal and then testing whether the proportion of negative correlations was significantly different from 50% (sign test) (Siegel, 1956).

Figure 1: Sites of wool sampling in NZ Wiltshire sheep as described in Table 1.
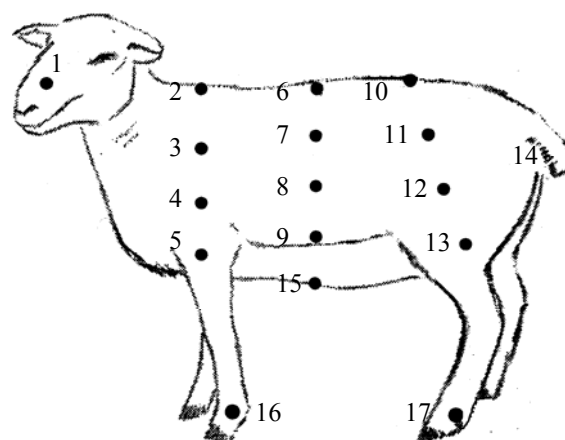
RESULTS

The characteristics of wool grown by Wiltshire rams varied considerably across the body. Staple length, mean fibre diameter, fibre diameter variation (Standard Deviation of Fibre Diameter or FDSD – as calculated by OFDA 100), and medullation from each site are presented in Table 1. As expected, wool (or hair) grown on the face and legs was distinctly different to that grown within the fleece bearing regions. Thus, short coarse fibres on the front (13 mm; 82 μm) and back (14 mm; 56 μm) legs, along with facial hairs (9 mm; 76 μm) highlight differences in major regional skin domains.

Within the fleece-bearing regions, staple length was longest on the shoulder (41 ± 2.5 mm) and shortest on the belly (14 ± 1.2 mm). An inverse correlation (R^2=0.7) between staple length and fibre diameter was observed within the finest fibres on the shoulder (27.8 ± 0.6 μm) and coarsest on the hip (33.8 ± 0.8 μm) (P<0.001). This gradient of

increasing fibre diameter was associated with increased within-staple variation ranging from FDSD of 5.3 ± 0.2 μm on the shoulder to 13.3 ± 0.9 μm on the hip (R^2=0.8; P<0.001). A mean within body site co-efficient of variation of 19.2 ± 1.1% on the shoulder and 39.8 ± 2.7 on the breech suggests the two-fold difference between fibres across the fleece is of a similar magnitude to the between-sheep variation which ranged between 20.4 and 48.6%. Showing a similar trend, fibre medullation increased from 7 ± 1% of fibres on the shoulder to 37 ± 4% of fibres on the hip (P<0.001). Wool grown on the breech was relatively short (18.9 ± 0.7 mm) making it comparable to that at the verge of the belly, but was considerably coarser (41.2 ± 1.7 μm) and had high proportion of medullated fibres (52.7%) reflecting a transition to the hind limb. Variation in fibre diameter within-staple (41%) and between-sheep (4.1%) were both higher on the breech than observed on any other site.

Although midside samples were representative for each fleece (31 ± 2.5 mm length; 28.5 ± 0.6 μm diameter; 21% medullation) they did not portray the anterior/posterior and dorsal/ventral gradients observed in all characteristics studied.

DISCUSSION

We have shown that a number of wool growth characteristics including fibre diameter, FDSD, length growth rate and medullation vary across the body. Across the fleece bearing regions these traits exhibit clear anterio-posterior and dorso-ventral

trends. Our results are in accord with previous reports on Merinos (Young & Chapman, 1958) and Romneys (Sumner & Revfeim, 1973) however the magnitude of variation is greater in Wiltshires than Romneys, with Merinos exhibiting the least variation.

Staple length also varied across the body of the Wiltshire sheep, forming gradients from the anterior to posterior and dorso-ventrally. Hence, the longest wool was found on shoulders while that on the belly, points and breech was shortest as also observed in other breeds (Lockart, 1954; Scobie, 2004; Young & Chapman, 1958). Large between-animal variation was observed in the present study. This is may reflect the prior outcrossing of Wiltshire Horns with other breeds (Poll Dorset) to reduce the incidence of horns when the breed was introduced to New Zealand. Due to minimal selection for wool production, considerable genetic variation in fibre length growth has remained within the AgResearch flock. Some care is needed in interpreting the staple length data as the time of natural commencement of wool growth during spring varies with site (by approximately two weeks between the back and belly (unpublished data)). Although the cessation of growth was synchronised by the photoperiod treatment applied, a variable duration of growth resulted. However the data is indicative of the growth observed in untreated Wiltshire.

In an inverse relationship to staple length, fibre diameter increased from the anterior to the posterior position of the fleece as well as decreasing dorso-ventrally. This is yet further

Table 1: Characteristics (mean ± between animal SEM) of wool grown over the photoperiodic-regulated follicle cycle in Wiltshire sheep for different body sites. †The overall mean for the fleece-bearing regions only is given. Seventeen sheep were included in the study.

Site	Staple length (mm)	Fibre diameter (μm)	Fibre diameter variation (μm)	Medullation (%)
1-face	9 ± 0.5	75.7 ± 2.0	33.4 ± 0.7	68 ± 3.2
2-shoulder	41 ± 2.5	27.8 ± 0.6	5.3 ± 0.2	7 ± 1.0
3	34 ± 2.3	27.6 ± 0.5	6.7 ± 0.5	12 ± 1.7
4	31 ± 2.2	28.0 ± 0.5	7.4 ± 0.7	17 ± 2.0
5	26 ± 1.7	28.3 ± 0.8	8.8 ± 1.1	20 ± 3.0
6-back	37 ± 2.6	29.6 ± 0.6	7.5 ± 0.6	17 ± 2.2
7	37 ± 2.3	28.6 ± 0.6	6.0 ± 0.3	16 ± 2.6
8-midside	31 ± 2.5	28.5 ± 0.6	7.1 ± 0.6	21 ± 3.3
9	20 ± 1.6	30.7 ± 0.7	13.0 ± 1.4	25 ± 2.4
10-rump	30 ± 1.9	30.6 ± 0.6	7.2 ± 0.7	24 ± 3.0
11	28 ± 1.6	31.5 ± 0.8	9.1 ± 0.9	30 ± 3.8
12	26 ± 2.1	33.9 ± 0.9	11.5 ± 0.8	34 ± 4.0
13	23 ± 1.7	33.8 ± 0.8	13.3 ± 0.9	37 ± 4.2
14-breech	18.9 ± 0.7	41.2 ± 1.7	17.0 ± 1.8	53 ± 4.0
15-belly	14 ± 1.2	30.8 ± 0.9	12.5 ± 1.2	25 ± 2.8
16-foreleg	13 ± 0.5	82.1 ± 3.0	35.0 ± 1.0	67 ± 3.1
17-hindleg	14 ± 0.7	56.8 ± 1.9	38.0 ± 0.9	54 ± 2.8
Mean †	**30.1 ± 0.7**	**29.9 ± 0.2**	**8.6 ± 2.6**	**21.7 ± 1.0**

evidence to dismiss claims that the ratio of fibre length and fibre diameter remains constant for an animal (Scobie & Saville, 2000). This pattern has also been observed in both Merino and Romney sheep (Denny, 1990; Lockart, 1954; Turner, 1956) where body site variations in fibre diameter contribute about half (Australian Merino (Dunlop & McMahon, 1974)) to three times (New Zealand Romney (Sumner & Revfeim, 1973)) the magnitude of the variance between sheep. Following a similar pattern, strong-wool strains of Merino have greater diameter variance compared with a fine-wool strain (Dunlop & McMahon, 1974; Olivier *et al.*, 1993). Thus, the within-animal variation observed in the present study is greater than for the breeds previously reported.

The number of medullated fibres is relatively high in Wiltshire sheep compared to other commercial breeds. However, the proportion of medullated fibres also varied greatly with body site. Not surprisingly, most fibres on the face and legs were medullated contributing to the coarse hair characteristic in these regions. Medullation in the fleece of the Romney has been shown to vary markedly with season (Scobie *et al.*, 1993) and independently of fibre diameter (Scobie *et al.*, 1998), and this also appears likely within the fleece of the Wiltshire. Across the fleece, gradients of medullation from the shoulder increasing several-fold to the lower hip and breech were observed. Thus high proportions of medullation within some regions resulted in fleeces with poor commercial potential.

Few studies have previously characterised wool harvested from the breech. There is increasing interest in the behaviour and growth of follicles in this region arising from the prospect of breeding animals with reduced fly strike risk while eliminating the requirement for crutching or mulesing. In the Wiltshire, breech wool is short and coarse with considerable variation in diameter (associated with high levels of medullation). Thus the wool on the breech exhibits growth characteristic of follicles from the ventral sites as well as the leg and provides sufficient between-animal genetic variation to exploit in the breeding of bare-breeched sheep (Scobie *et al.*, 2006).

Our results support the consensus that the midside position is a suitable choice for the measurement of mean fleece characters over the fleece bearing regions as reported in other sheep breeds. On the other hand, such a sampling regime gives no indication of the between-region variation in wool grown. For some experimental purposes it may be advisable to determine length growth rate using the method of Scobie (2004), concurrent with other sampling protocols such as determining

cell division rate in follicles or histological analysis of follicle activity.

There is increasing interest in the molecular mechanisms that underlie these variations in wool follicle growth across the body. Studies in other species indicate that hairs transplanted from one body region to another retain characteristics of the embryonic origin of those hairs. Differences in expression of key developmental regulators at critical stages of follicle morphogenesis may set in motion a programmed growth pattern that culminates in wool specific to each region. One family of genes shown to contribute to regional specificity of hair growth are the homeodomain genes. Tbx15 has been shown to influence the dorso-ventral pattern of pigmentation in mice (Candille *et al.*, 2004). Msx1 and Msx2 homeodomain proteins have been shown to influence regional specification of feather and scale tracts in birds (Chuong *et al.*, 1996; Kim *et al.*, 2005), specification and development of skin (dermis) domains and regional hair cycle patterns in mice (Ma *et al.*, 2003). Furthermore, we have shown that Msx gene expression in the skin varies across the body of the developing lamb at critical times of primary and secondary wool follicle initiation (Craven *et al.*, 2007). Regional variations in Msx2 expression are maintained into adulthood where they may differentially modulate the differentiative processes of keratins within the wool shaft. Undoubtedly, further regulatory factors act in concert to modulate each follicle in spatially specific program. As a result patterns of wool growth across the body are produced. Sometimes clear boundaries between these regional domains exist – as seen between the fleece and face or legs. Alternatively, small graduated variations occur and are observed only following close examination such as those in this study, and result in the anterio-posterior of dorso-ventral patterns of wool production.

The genetic nature of these skin domains has been exploited in breeding programs to produce sheep with clearer demarcation of fleece growth around the face, belly and breech (Scobie *et al.*, 2006). Further understanding of these patterns of within fleece variation in wool characteristics will be useful in producing sheep with desirable fleece distribution patterns.

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