Growing wool

Genetic Alternatives to Mulesing and Tail Docking in Sheep

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Summary

There appears to be significant opportunity to reduce the susceptibility of Merinos to breech strike by genetic means although it appears unlikely that breeding alone will be able to confer the degree of protection provided by surgical mulesing and tail docking, at least in the short term. Breech strike control generally consists of an integrated approach which may include mulesing, tail docking, crutching, control of scouring through nutritional management and good internal parasite control, strategic shearing, preventative application of insecticides and treatment of struck sheep. Any breeding program which seeks to replace surgical mulesing and tail docking will need to make sheep sufficiently resistant that the increased requirement for other strike management procedures remains within practically acceptable bounds.

Currently used mulesing techniques gain their efficacy from three major effects:
- Removing wrinkles that are liable to urine staining and faecal fouling
- Stretching the area of bare perineal skin beneath the tail
- Removing wool bearing skin from the sides and end of the tail and near the tail base.

Docking tails to the correct length assists the prevention of wool staining and consequent tail strike. The optimal length for tail docking is level with or slightly below the tip of the vulva.

Breeding programs that aim to replace surgical flystrike prevention techniques could potentially:
- Reduce breech wrinkles
- Increase the area of bare perineal skin
- Reduce tail length and wool cover on the tail
- Increase shedding of breech wool
- Reduce susceptibility to scouring
- Increase immunological resistance to invasion by blowfly larvae.

Breech wrinkle

Breech wrinkle is highly heritable and can be readily reduced by breeding. However, selection against skin wrinkle has been practiced in the Australian Merino flock over many years and even sheep with very plain breeches benefit from mulesing. Further gains in breech strike resistance may be possible by selection against breech wrinkle in some flocks, although the potential for significant improvement by this means appears limited in most cases.

Area of bare perineal skin

Selection within breed: There is only one (preliminary) estimate available of the heritability of breech bare skin area. This estimate suggests that bare skin area is moderately heritable. Further estimates are needed to properly assess the rate of improvement possible by direct selection. These could be obtained from Merino genetic resource flocks or other pedigreed flocks at relatively low cost.

Extreme phenotypes: Occasional " extreme phenotypes" for bare area within the Merino breed have been reported. One such line of animals has been reported from Calkookara stud in South Australia. These sheep offer the possibility of increasing the area of bare skin in the breech without the need for the introduction of non-Merino genes and should be investigated further to ascertain:
- Degree of bare area present
- Susceptibility to urine staining, faecal contamination and breech strike
- Mode of inheritance and potential for breeding to achieve rapid genetic gains

- Any deleterious or unfavourable associated effects.

In addition, wool producers should be canvassed industry-wide for other instances of sheep with unusually bare breeches.

Distribution of wool bearing skin on and near the tail: Wool growing near the tail root and on the sides and end of the tail can become stained with faeces and urine, particularly as the wool grows longer. The anus is located closer to the tail wool than the vulva and staining is particularly a problem when sheep are scouring. With increased importance of scouring as a predisposing cause of breech strike in present day sheep production systems the pattern of wool growth on and around the tail will be a significant consideration in any breeding strategy that seeks to replace mulesing. However, to date the extent of natural variation amongst sheep in wool cover on and near the tail has received little consideration.

Intercrossing with other breeds: Some breeds of sheep have naturally large bare perineal areas. These are generally not high wool producing sheep and there are no reports of the mode of inheritance of bare skin area in these sheep. Intercrossing to increase bare skin in Merinos is a possibility but would require significant selection or backcrossing to regain wool cut and quality.

Tail length

Worldwide, there are many breeds of sheep that have naturally short tails. There are also many reported instances of sheep from otherwise long tail breeds being born with very short or missing tails. However, there appears to be no example to date of successful selection to incorporate the short tail trait into an established domestic breed. Tail conformation and the disposition of wool on and above the tail will influence flystrike susceptibility and will also need to be taken into account in any breeding program to reduce tail length.

Selection within breed: Estimates of the heritability of tail length in non-Merino breeds and in other species are moderate to high. This suggests the possibility of relatively rapid reductions in tail length from selection within breed, although no estimates of heritability exist for Merinos. However, whether mean length and variability could be reduced to practically acceptable levels is unclear. Although not a high priority, estimates of heritability of tail length in Merinos could be easily and cheaply obtained from Merino resource flocks and may assist an assessment of the feasibility of reducing tail length by this means.

Extreme phenotypes: There are many reports of animals born with short tails or no tails in otherwise long tail breeds. In most instances the trait seems to be determined by one or a few genes of major effect. In nearly every instance where inheritance has been investigated in these animals it seems that the trait was associated with increased incidence of deleterious effects, for example spinal cord abnormalities, urogenital tract malformations, embryonic death, atresia ani. Further studies of sheep with rare short tail phenotypes should be structured to allow early identification of deleterious effects.

Short tail breeds: Inheritance of tail length appears to be multigenic in most naturally occurring short tail breeds. Crossbreeding long tail breeds with these breeds gives rapid reduction in tail length in the early crosses. Introduction of genes from other breeds is likely to be the most rapid means of reducing tail length in Merinos. However, at least in the early stages it is likely that cross breeding will compromise the wool producing attributes selected over many years in Merinos. In addition, as tail length appears to be multigenic, a degree of variability will remain in the intercrosses. Whether tails could be reduced to a practically acceptable and sufficiently uniform length so that docking is not required is uncertain.

Shedding of breech wool

Crossbreeding Merinos with Wiltshire horn sheep produces animals that shed wool in the breech area and have reduced susceptibility to breech strike. Backcrossing to Merinos improved wool quality but also increased strike susceptibility. There is a possibility that the shedding character could be introduced to Merinos without loss of wool quality by appropriate breeding strategies. However, if indeed possible, it seems likely that it would take some time to achieve practical levels of breech strike protection.

Selection for resistance to internal parasites, low dag score and immunological resistance to blowfly larvae

Selection for internal parasite resistance has been successfully achieved in a number of flocks although the effect on scouring and the production of dags has been variable. Propensity to scouring and dag formation has been shown to be heritable and should respond to selection. The potential for selecting for immunological characteristics that increase resistance to invasion by blowfly larvae is uncertain at this stage but is presently under consideration. Selection against propensity to scouring and, potentially, for resistance to blowfly larvae, will contribute to reduction in breech strike susceptibility.

General

A genetic solution to breech strike control is attractive as it is potentially permanent, cumulative, does not involve increased use of chemicals and may ultimately reduce labour inputs. Selection within the Merino breed for increased bare skin in the breech and short tails has not been attempted and offers the possibility of modification without the complication of introducing undesirable non-Merino genes. However, whether sufficient variation is present within the Merino breed to make practical improvements in breech strike resistance or reductions in tail length is uncertain. Incorporation of major genes of large effect will be the most convenient and achievable way to proceed if suitable genes can be found.

While intercrossing with other breeds may be the most rapid means of increasing breech strike resistance and reducing tail length, this approach is also likely to compromise many of the desirable production attributes of Merinos. This is especially so where the inheritance of the attributes being selected is quantitative in nature. Depending on genetic relationships between the different characters under selection it may take many generations to regain the wool producing capacity of present day Merinos. Ultimately, regardless of which approach is taken, it is likely that there will need to be a trade off between the requirement for alternatives to surgical mulesing and tail docking and other production imperatives.

Introduction

Although sheep have been farmed in Australia since the first fleet in 1788, flystrike was seldom a significant concern before the early 1900s. The Joint Blowfly Committee in (1933) summarises the earliest reports of strike in each of the states as ranging between 1870 in Tasmania and 1900 in South Australia. However they note that it was not until the early 1900s that flystrike became a problem over the greater part of the sheep country of Australia. It is notable that *Lucilia cuprina* probably did not enter Tasmania until the 1950s and earlier strike records were probably due to native flies (Ryan 1954). The emergence of strike as a major industry problem seems to have coincided with two major events, the introduction of the so-called Australian sheep blowfly, *L. cuprina*, probably from Africa, and the introduction of the extremely wrinkly Vermont Merino from the USA in the late 1800s (Cameron 1999).

Breech strike is the major form of flystrike in most years even though body strike can cause major problems in wet seasons or during prolonged periods of warm wet weather (Belschner 1937, Watts et al. 1979, Murray 1980, Murray and Ninnes 1980, Murray and Wilkinson 1980). Breech strike occurs when the wool in the breech area of sheep becomes stained and is kept moist by urine or fluid faeces, causing inflammation of the underlying skin and bacterial growth. This produces an odour that attracts the female fly and stimulates her to lay eggs. The wetted wool provides suitable conditions for the eggs to hatch and the scalded skin provides protein and a focus for invasion by the newly hatched maggots. Breech strike is often divided into crutch strike, involving the region below the tail base extending on both sides of the bare area down to the distal border of the udder or scrotum, and tail strike, which involves the body of the tail, frequently originating on the stump or sides of the tail (Watts and Marchant 1977). This definition will be used here as the distinction is important to a consideration of genetic alternatives to mulesing and tail docking.

The importance of breech wrinkle in determining susceptibility to strike was recognised very early in the history of the sheep industry (Froggat 1915, Seddon 1931, Seddon et al. 1931, Bull 1931, Joint Blowfly Committee 1933). This stimulated the development of the earliest form of the mules operation by a South Australian Grazier, Mr JWH Mules in 1931. The exceptional effectiveness of the mules operation has led to it being the keystone procedure in integrated flystrike control programs. Dr WIB Beveridge, an early flystrike researcher, in an article on the origin and early history of the mules operation describes the operation as “one of the most important disease measures discovered in Australia” and comments that “many of the younger sheepmen today do not fully appreciate what a severe problem blowfly strike was in the days before the mules operation”(Beveridge 1984).

There is a growing trend for consumers to require that goods be produced in quality assured, environmentally benign and ethical production systems and often this requirement extends to animal welfare considerations. Mulesing and tail docking are of increasing concern in this context and indeed most woolgrowers would prefer not to mules if a viable alternative could be found. Despite many efforts by the industry in the past to develop a non surgical method (Morley 1949, Pratt and Hopkins 1976, Sorrell et al. 1990, Chapman 1993) and ongoing projects (PI Hynd pers. com.) to date a viable alternative has not been found.

Breeding sheep with reduced susceptibility was one of the earliest approaches to flystrike control and has continued to be an element of most Merino breeding programs (Seddon et al. 1931, Belschner 1937, Seddon and Belschner 1937b, Atkins and McGuirk, 1979, Raadsma and Rogan 1987, Mortimer 2001). However, because of the exceptional effectiveness of mulesing in controlling breech strike, such efforts have concentrated more on resistance to body strike than resistance to breech strike. More recently the need for breeding approaches that increase resistance to breech strike and reduce the need for mulesing and tail docking or other stressful procedures has been indicated and research towards this end is underway (Scobie et al. 1997, 1999, Karlsson et al. 2001). Genetic modification through conventional selection approaches or through gene manipulation, if suitable genes can be identified, is an appealing possibility as it is potentially permanent, does not rely on heavy use of chemical pesticides and could ultimately reduce labour requirements for flystrike control.

Development of the mules operation

Mulesing and tail docking are conducted primarily to protect sheep against the debilitating and potentially lethal effects of flystrike, but also confer significant other benefits including reduced wool staining, dags and consequent reduced requirement for 'crutching', improved ease of crutching, reduced labour requirement for inspecting flocks and treating struck animals, lower chemical residues in wool, and the ability to time shearing to optimise wool quality rather than minimise flystrike incidence. The mules operation as originally conceived by Mr JWH Mules in 1931 was primarily a procedure to remove breech wrinkles. However, as our knowledge of breech strike and the features that determine susceptibility has grown, the operation has changed significantly. These changes have been well reviewed by Morley and Johnstone (1984) but a brief overview is given here to aid consideration of the features that may be required in sheep with genetically increased resistance to breech strike.

Early studies identified the importance of breech folds in determining susceptibility to strike (Seddon et al. 1931) and early mulesing techniques were aimed primarily at removing these folds. Largely as a result of the Vermont influence most Merinos of that time had quite extensive wrinkling in the breech area and in particular a pair of medial folds that ran vertically along each side of the perineal area. The operation first described by Mr Mules consisted of clamping the folds with 'Burdizzo' pincers, a procedure that was thought to paralyse the nerve endings, and then excising them with a knife (Bull 1931, Beveridge 1984). A subsequent modification was the use of roll cut secateurs and adapted dagging shears, which improved utility of the operation.

Further experiments showed that this method removed insufficient skin to reduce the susceptibility of wrinkly animals to that of plain-bodied sheep (Johnstone and Graham 1941, Graham et al. 1941, Joint Blowfly committee 1943). In light of this information the original technique was developed to the modified mules operation, which removed more skin and had the added objective of stretching the bare skin of the crutch, particularly below the vulva. This was achieved by excising two crescents of skin along either side of the bare perineal skin, the cuts starting about 2.5 cm above the butt of the tail and finishing on the inside of the leg just above the top of the hamstring (Johnstone and Graham 1941, Graham et al. 1941, Joint Blowfly Committee 1943).

Although the modified mules improved protection against true breech strike there was little effect on the incidence of tail strike. The importance of tail length in determining susceptibility to strike in unmulesed and modified mulesed sheep was recognised at this time (Gill and Graham 1939). Butt tailed or very short tailed animals could not hold wool from above the tail out of the way when defaecating or urinating and it was found that as the wool on the tip and sides of the tail grew longer it hung down into the urine stream, becoming stained and susceptible to strike.

Graham and Johnstone (1947) removed an additional strip of skin from the centre of the top of the tail to stretch the bare ventral tail skin over the sides and reduce the likelihood of staining. Animals treated by this method still suffered low levels of strike because of staining of wool growing from folds left at the base of the tail or that hung down from the tail stump (Dun 1954). The technique was further modified by a grazier Mr Bill Sutton of Bundemaar Station to what became known as the radical mules operation (Morley and Johnstone 1984). In the radical mules all skin was removed from the top and sides of the tail and the cuts of the tail and crutch operations were joined so that no wool grew between them. This method was highly effective in preventing strike and could be used with a shorter tail than the modified mules, making these sheep easier to shear and crutch than sheep with longer tails.

However, radical mulesing with a short tail exposed the perineal skin and sensitive vulval and anal tissues to sunburn and was associated with an increased prevalence of rear end cancers (Vandegraaf 1976, Hawkins et al. 1981, Swan et al. 1984). For this reason, in the 1970s the operation was further modified to the 'V' mules, most commonly recommended today (Yeo 1979). This method is similar to the radical mules in that the tail and breech cuts join up, but a V of wool bearing skin is left on top of the tail to provide protection against sunburn.

Extensive surveys during the 1970s of flystrike occurrence in New South Wales (Watts et al. 1979), Western Australia (Murray and Wilkinson 1980), South Australia (Murray and Ninnes 1980), and Victoria (Murray 1980) suggested that the nature of the breech strike problem had changed significantly from that in the earlier part of the century. While earlier studies (Joint Blowfly Committee 1933, Belschner 1937) suggested that urine staining was the major predisposing factor, the more recent surveys suggested that scouring, associated with grazing improved pastures and higher stocking rates had increased markedly in importance. In contrast to the situation with urine staining, tail length was found to be very important in determining strike susceptibility in scouring sheep, even when sheep were radically mulesed (Watts and Marchant 1977, Watts and Luff 1978, Watts et al. 1979). A medium-long tail (docked to three joints or tip of the vulva) became recommended in radically mulesed sheep, both to reduce flystrike susceptibility in scouring sheep and to provide protection of the sensitive vulval and anal areas against sunburn and cancer.

Although the mules operation was originally developed to protect wrinkly breeched Merinos, the considerable benefits to non-Merino plain breeched sheep have also been recognised (Richardson 1970, Reid and Jones 1976, Lear and Faulkner 1977). The operation is now routinely applied to many non-Merino flocks and to first cross prime lamb mothers (Lottkowitz et al. 1984, Morley and Johnstone 1984).

From the foregoing discussion it appears that any genetic modification to approximate the effect of surgical mulesing and tail docking would desirably include:

- Few (no) skin folds in the breech region
- Increased area of bare perineal skin
- Tail length that enables the sheep to hold wool out of the way when defaecating or urinating
- Short (no) wool on the ventral surface, sides and tip of the tail and near the tail base.

These features are considered in more detail in the following section. However, they should not be thought of as all or none characteristics. There will be considerable interaction in their effect and particularly good conformation in one area may compensate for less than optimal form in another. It will also be extremely important to ensure that the tail is long enough to protect the vulval and anal areas from sunburn, that any genetic change in conformation does not render animals more susceptible to cancer or to any genetic disorder and desirably, that selection for resistance traits does not confer any production disadvantage.

Sheep factors influencing susceptibility to breech strike

Breech wrinkle

The role played by breech folds in susceptibility to flystrike was recognised very early. The Joint Blowfly Committee 1933 quote a number of early articles (Froggat, 1915, Froggat and Froggat 1916, 1917, 1918) in which it is noted that the production of a type of sheep with wrinkled skin and dense wool were significant factors in the emergence of flystrike as a major problem. Bull (1931) noted "for many years, sheep breeders, probably more particularly those in South Australia, have realised that the plain bodied sheep is less susceptible to attack by blowfly than the wrinkly sheep". More particularly, the introduction and extensive intercrossing of the Vermont sheep in the latter half of the 19th century was of major importance. The Joint Blowfly Committee (1933) describe the breech conformation of the Vermont as follows: "the skin of the rump is so arranged that the tail is wide and flappy with a marked central depression and the skin of the breech (ie at the sides of the anus and vulva) and crutch (perineum) is folded or wrinkled in a more or less irregular manner". Seddon and Belschner (1937) give a much more detailed description of the various skin folding patterns that can occur in the breech and around the tails of sheep and discuss their role in determining susceptibility to strike.

The Joint Blowfly Committee (1933) noted that where 'out folds' are consistently exposed to urine and faeces staining, skin scalding can occur leading to dermatitis and continual moist exudation. In addition, urine, and other moisture can collect in the 'in folds' and bacterial decomposition of yolk, sweat and skin detritus can occur, producing an odour attractive to flies and a protected moist environment suitable for maggot growth. Bull (1931) provides a description of histological changes and bacterial growth in the skin of breech wrinkles collected from stained sheep. He concludes that "the serous and sometimes sanguinous exudate on the surface of the skin would offer excellent pabulum for the blowfly larvae" and "would also prove attractive to the flies". It was also noted that other factors such as greater liability to cuts at shearing and crutching, greater liability to grass seed infestation and heavy wool yolk content also contributed to increased susceptibility.

Early studies showed that liability to strike was broadly parallel to the degree of wrinkling in the breech area and that susceptibility to breech strike was repeatable with the same sheep likely to be restruck each season. Seddon et al. (1931) divided sheep into broad categories described as A, relatively insusceptible, B, moderately susceptible and C, definitely susceptible on the basis of breech conformation. Seddon and Belchner (1937) later provided a detailed description of features of sheep in the three classes. Good correlation between this classification and susceptibility to strike was demonstrated by Seddon et al. (1931) who reported that A, B and C class sheep had 26%, 59% and 125% incidence of strikes respectively over two fly seasons. The Joint Blowfly Committee (1933) reported strike rates of 4.8%, 15.4% and 50% respectively over one year and Mackerras (1936) reported incidence of 26%, 94% and 175% over three years.

Bare area

Effect of mulesing

It is now well recognised that mulesing has effects in addition to removing wrinkles and is also beneficial to plain bodied and non-Merino breeds. Benefits from mulesing Corriedales were indicated as early as 1947 (Graham et al. 1947) and Richardson (1970) reported a reduction in strike incidence from 35.4% to 2.5% in mulesed comeback ewes. Reid and Jones (1976) treated Corriedale and Border Leicester x Corriedale ewes by the radical mules and modified mules operations and observed incidences of strike over a 20 month period of 3.8% and 19%

respectively in the Corriedales and 1.0% and 4.8% respectively in the crossbreds. This compared to 60.9% in unmulesed Corriedales and 30.5% in unmulesed crossbreds. Increased area of bare perineal skin which renders sheep less liable to urine staining and dags (Johnstone and Graham 1941, Reid and Jones 1976) is probably the major effect conferring protection in these breeds.

Table 1 below summarises studies in which the dimensions of the bare perineal area have been measured. A consideration of these studies suggests that mulesing increases the width of the bare skin area by approximately 2-2.5x, but most methods only have a small effect, if any, on vertical dimensions.

A number of the studies summarised in Table 1 compared the size of the bare areas produced by different mulesing techniques. Morley (1949) compared sheep treated by the modified mules operation with those treated by the modified mules plus tail strip as described by Graham and Johnstone (1947). Sheep with tails docked short or level with the tip of the vulva were included in this study. Neither application of the tail operation nor docking length appeared to have any effect on the resultant bare area width and neither mulesing method had any significant effect in increasing vertical bare area dimensions in comparison to unmulesed sheep. In contrast, Watts and Marchant (1977) found that butted tailed sheep treated by the modified mules had a significantly wider bare area than long tailed sheep. Interestingly, in Morley's study sheep treated by the Manchester method, an early chemical method which used application of caustic potash, had the largest bare areas of all and had significantly greater vertical bare area dimensions than either surgically mulesed or unmulesed animals.

Table 1: Dimensions of bare perineal area in mulesed and unmulesed sheep (cm)

Study	Type of mules	Sheep	Age mulesed	Age measured	Where measured	Width of bare area mulesed	Width un-mulesed	Depth of bare area mulesed	Depth un-mulesed
Morley 1949	Modified and Modified plus tail treatment	Adult ewes	16 and 20 mth	8.5 mths after treatment	Base of tip of vulva	6.1-6.9	2.8	1.5-2.1	1.5
Moule (1955)		Ewe lambs	Lambs, age not specified	"Lamb" 1 mth after mulesing		10	3.7		
Roberts 1969 (unpublished)	Radical		Lambs	Hoggets	Widest point	9.4-10.7		3.0	
O'Halloran et al. (1983)	Various	Ewe lambs	Marking	9 mths 28 mths	Midway of vulval orifice, from anus to wool below	9.5-12.5 13.8-16.7	 8.25	4.9-5.6 7.1-8.6	 8.75
Bell et al. (1983)	Radical or V	Wethers	Marking –3weeks	12-13mths	2.0 cm below anus	9.0-9.9		2.9-3.3	
May et al. (1983)	Radical or V	Ewes and wethers	10 mths	14 mths	2.0 cm below anus	Ewes 10.0-10.6 Wethers 8.8-9.0			
Watts and Marchant 1977	Modified mules	Ewes and wethers	2-8 wks	Hogget	Below anus	Ewes 7.9 Wethers 6.9		Ewes 6.3 Wethers 5.2	

A series of papers in the Second National Symposium on Flystrike describe the results of different techniques of mulesing in terms of the area of bare skin and tail length achieved (O'Halloran et al. 1983, Bell et al. 1983 and May et al. 1983). Mulesing techniques that were considered unlikely to lead to an acceptable result were deliberately included in the study of O'Halloran et al. (1983). The major factor influencing the dimensions of the bare perineal region was the number of cuts made on each side of the perineum. Similar numbers of cuts on each side seemed to give similar bare area widths regardless of technique, except where wool was left between the cuts and the bare skin or where the mulesing cuts encroached into the bare area. As in the study of Morley (1949) the configuration of cuts over the tail had little effect on bare area measurements. The only treatment that had a significant effect on vertical dimensions was joining the cuts below the perineal skin. Even in the worst case with only one cut either side of the perineal skin, bare area width was increased by 1.5 times. No assessment was made of the relative degrees of protection provided against strike by the various methods and most of these studies paid little attention to the pattern of wool bearing skin left on or around the tail.

Distribution of wool bearing skin on and near the tail

Wool growing near the tail root and on the sides and end of the tail can become stained with faeces and urine, particularly as the wool grows longer. The anus is located closer to the tail wool than the vulva and staining is particularly a problem when sheep are scouring. With increased importance of scouring as a predisposing cause of breech strike in present day sheep production systems (Watts 1979, Watts et al. 1979) the pattern of wool growth on and around the tail will be a significant consideration in any breeding strategy that seeks to replace mulesing. The modified mules operation removes wrinkles in the breech area and provides a similar amount of stretching as the radical mules, but the radical mules, which also removes skin from around the tail base and the dorsal surface of the tail, provides a higher level of protection against strike than the modified mules. In sheep with tails docked to the tip of the vulva, Dun (1954) recorded strike incidences of 75% and 39% in Spring and Autumn respectively in sheep that were not mulesed, compared to 15% and 4% for sheep treated by the modified mules and only 2.4% and 1.2% for sheep treated by the radical mules. In the study of Morley (1949) incidence of strike in two fly periods in sheep with medium long tails was 68.9% and 36.7% in unmulesed sheep, 10.5% and 11.3% in the modified mulesed group and only 1.1% and 1% in those treated by the modified mules with tail operation, even though the areas of bare skin in the two mulesed groups were similar. Significantly, in the modified mules operation, which stretched the bare area but did not remove skin from the tail, the majority of strikes were tail strikes (70% in spring and in 55% autumn).

Morley developed the following scoring system for assessing the distribution of wool on the tail:

1. Wool bearing skin well onto the ventral surface of the tail
2. Wool bearing skin covering fully the sides of the tail
3. Wool bearing skin half covering the sides of the tail
4. Bare skin covering the sides of the tail
5. Bare skin projecting well onto the dorsum of the tail.

Three scores were assigned for each animal, one for each side of the tail and one for the tip. In sheep with medium long tails the average scores were 6.4 for those not mulesed, 6.3 for the mules with no tail operation, 13.3 for the mules and tail strip and 14.9 for those treated by the Manchester method. As the wool grew longer on the sides and above the tail the modified mulesed sheep without the tail treatment became stained and attractive to flies. This problem was most acute when tails were docked short and the sheep were not able to lift their tail and hold the wool out of the way when defaecating and urinating.

Even in radically mulesed sheep, if tails were cut too short, wool near the base of the tail could flop over the anus and was not elevated clear of the scouring stream (Watts and Luff 1978). A medium tail that was bare of wool in radically mulesed sheep formed a natural channel and prevented the breech and tail wool from covering the anus, but was susceptible to sunburn. The V mules provided protection against sunburn but still removed the wool from near the tail base and parts of the tail where it was likely to become stained (Yeo 1979). Recommendations were that the V of wool bearing skin be left to cover most of the tail in areas with high incident solar radiation and limited incidence of scouring, but left further back from the tail tip in higher rainfall areas where scouring was more common and there was a chance of the wool becoming stained as it grew longer.

O'Halloran et al. (1983) note that regardless of the mulesing method used, if it is to be effective in protecting against strike it must prevent the wool hanging over the sides or ends of the tail where it could become soiled and liable to flystrike. In addition, as noted earlier, when tails are longer wool on the ventral surface can become stained and susceptible to strike (Joint Blowfly Committee 1943, Graham et al. 1947, Scobie et al. 1999). It seems that the ideal tail for ease of management and flystrike protection should have no, or only short wool on the ventral surface, sides and near the base of the tail to minimise wool staining.

Natural variation in the area of bare perineal skin

There have been few studies of the degree of natural variation in bare area dimensions or relating the area of bare skin to flystrike susceptibility. It is well known that males generally have smaller bare areas than females, but it is hard to draw conclusions about effects on susceptibility to strike resulting from this difference in most cases because of the complicating effects of urine staining in females. However in the study of Morley et al. (1949) where the main predisposing factor was scouring significantly more wethers (49%) than ewes (25%) were struck and this was attributed to a smaller bare area in the wethers. Watts and Luff (1978) report similar results in scouring sheep with 27% of wethers struck compared to 13% in ewes. This difference was attributed to difference in bare area dimensions of the two sexes with ewes having bare areas 7.0 cm wide and 4.5 cm in depth as compared to 6.0 cm by 3.7 cm in wethers. A similar effect was observed by Scobie et al. (1999) who found that (unmulesed) male Coopworth lambs accumulated significantly more dags than females.

Scobie et al. (2002) scored the area of bare skin from 1 (little or no bare perineal skin) to 5 (largest bare area), in groups of sheep of a variety of breed backgrounds. At weaning, animals with an average body weight of 23 kg and score 5 bare areas had an area of bare skin of about 50cm^2. Breed types included in this study were Perendale, Finish Landrace x Romney, Finnish Landrace x Dorset Down and three composite breeds, one based on crosses of Finnish Landrace x Cheviot, one based on the Wiltshire and the other based on a feral x Merino sheep. All of the score 4 and 5 animals in the study were Wiltshire horns and none of these animals were struck. Litherland et al. (1992) also found Wiltshire Horns (WH) to be more resistant to strike than Merinos in New Zealand and Rathie et al. (1994) in Queensland found a lower incidence of flystrike in Wiltshire Horn x Merino ewes than in pure Merinos. However, no measurements were taken of the size of the perineal region in these studies and the degree to which reduced susceptibility was due to a larger bare area or to shedding of the breech wool is uncertain.

Even after the Wiltshires were excluded from the analysis of Scobie et al. (1999) there was still an effect of bare area dimensions on strike in two of the experiments ($P<0.05$ in one experiment and $P<0.1$ in the other). Excluding the Wiltshires, over all the lambs in the three experiments the proportion of struck animals was 22% for bare area score 1, 16% for score 2 and 11% for score 3. These results suggest that increasing the area of bare skin by breeding would reduce susceptibility to breech strike, although it is unlikely, at least in the early stages of a breeding program, that the level of protection would approach that provided by surgical mulesing.

Table 2: Bare area dimensions in a flock of South Australian Merinos (cm) (James et al. unpublished)

Measure	Sex	Mean	Standard deviation	Min	Max
Birth					
Width at anus	F	2.27	0.36	1.5	3.6
	M	1.75	0.33	0.9	3.0
Width at vulva	F	2.07	0.43	1.0	3.5
	M	0.70	0.31	0.1	2.4
Length	F	3.43	0.48	2.1	5.1
	M	2.26	0.50	1.2	4.3
Marking					
Width at anus	F	3.07	0.69	1.2	5.1
	M	2.48	0.50	1.3	4.4
Width at vulva	F	2.76	0.72	1.0	4.8
	M	2.07	0.48	1.1	3.7
Length	F	5.10	0.87	2.7	7.3
	M	3.71	0.83	1.8	6.5
Post mulesing					
Width at anus	F	9.28	1.88	2.0	14.0
	M	6.99	1.75	3.0	11.0
Width at vulva	F	6.98	1.71	3.0	12.5
	M	6.11	1.85	2.2	11.5
Length	F	5.05	0.84	2.9	8.3
	M	3.91	1.20	1.2	8.2

There appears to be even less information available about the degree of variation in bare area dimensions within breeds, and more particularly, within the Merino breed. None of the mulesing studies noted above in which unmulesed animals have been measured present measures of variability, so it is not possible to estimate the likely ranges of natural bare area dimensions present. The only data for variability within Merino populations appears to be that of James et al. (unpublished) who measured bare area dimensions of South Australian Merino lambs at birth and prior to marking. Table 2 gives the mean and standard deviation of bare area dimensions in these lambs, as well as post mulesing measurements in ewes and a subset of wethers. These results suggest that the coefficient of variation of bare area dimensions in unmulesed sheep is approximately 20-25%, approximately similar to that for most quantitative production traits.

Tail length

Tail length is known to have marked effects on flystrike susceptibility in both mulesed and unmulesed sheep. As early as 1939 Gill and Graham noted that the incidence of strike in sheep with tails docked short was higher than in those with longer tails. This was confirmed by Riches (1941, 1942) who recorded the incidence of strike in groups of unmulesed sheep experimentally docked to three different lengths, (long - docked to approximately four inches in length, medium - docked to two joints and short - docked level with the buttocks) or left undocked. He suggested that longer tails tended to press the breech wool apart leaving better clearance for urination and might allow the animal to twitch its tail to deter flies. There are many other studies that also show a clear advantage for leaving the tail longer in unmulesed animals (Graham et al. 1947, Moule 1955, Joint Blowfly Committee 1943). The results of Riches (1941,1942) are cited below in Table 3, not only because they are typical of results achieved in unmulesed animals, but also because they include sheep with undocked tails.

Table 3: Number of strikes per hundred sheep in animals with short medium long or undocked tails in the two years of the study (Adapted from Riches 1941, 1942)

		Short	Medium	Long	Undocked
Riches 1941	Expt 1	61.0	55.9	32.2	Not measured
	Expt 2	35.6	28.0	8.4	12.1
Riches 1942		90.4	60.9	24.8	41.3

Although the sheep with undocked tails had a lower incidence of strike than sheep with short or medium tails it was noted that the undocked tails often became very stained near the ends and sometimes also resulted in the hocks becoming badly stained (Riches 1941, 1942). More recently, French et al. (1994) reported that undocked British breed sheep in the south west of England had a higher incidence of faecal soiling than sheep with tails docked to cover the vulva in ewes or the anus in wethers. In their studies undocked sheep also had a significantly higher incidence of breech strike than sheep with docked tails. Similar results were reported in Victoria by Webb Ware et al. (2000) who found that prime lambs with tails left undocked were significantly more liable to the development of dags and on one farm were at three times the risk of breech strike compared to lambs with tails docked to the tip of the vulva. Scobie et al. (1999) docked tails of unmulesed Perendale and Coopworth lambs to 6 different lengths varying from level with the butt to level with the hocks and found that increasing the length of tail increased the accumulation of dags for the Coopworth, though not Perendale lambs.

In sheep treated by the modified mules there was still a clear advantage for tails docked longer over those docked short (Watts and Marchant 1977). However, in the studies of Graham et al. (1947) where tails were docked to half an inch below the margin of the bare area there tended to be a slightly higher incidence of urine staining, dag formation and strike than in animals docked medium long (just below the tip of the vulva). The authors also noted a tendency for longer tails to become attached to the crutch by burrs and more subject to staining because of this. The Joint Blowfly Committee (1943) noted that under no circumstances should the tail be docked below the ventral area of bare skin as this left wool on the underside of the tail that could become urine or faeces stained and susceptible to strike. In addition, tails cut too long tended to stick out or up and made crutching and shearing more difficult. A tail cut level with the tip of the vulva became that most commonly recommended with the modified mules operation (Morley and Johnstone 1984).

The radical mules operation was considered to give almost complete protection against strike, regardless of tail length (Dun 1952). Short tails were widely used with this technique because of the greater ease of crutching and shearing. However, it seems that this recommendation was mainly applicable to conditions where sheep were grazing unimproved pastures and urine staining was the major predisposing factor.

From a survey of blowfly strike in NSW in the 1970s, Watts et al. (1979) concluded that the nature of the strike problem had changed significantly from that in earlier years. Earlier studies (Joint Blowfly Committee 1933, Belschner and Seddon 1937) suggested that urine staining was the major predisposing cause for breech strike whereas Watts et al. (1979) found that although urine staining was still important, scouring associated with grazing improved pastures had become a significant predisposing factor. Breech strike exceeded 5% in 14% of radically mulesed flocks where scouring had occurred and was generally associated with tails cut too short. Surveys in South Australia (Murray and Ninnes 1980), Western Australia

(Murray and Wilkinson 1980) and Victoria (Murray 1980) reached similar conclusions. Experimental studies confirmed that sheep with tails docked short, whether treated by the modified mules, radical mules or unmulesed, were more susceptible to strike when scouring (Watts and Marchant 1977, Watts and Luff 1978). These findings, together with recognition that a very short tail exposed the delicate vulval and anal tissues to sunburn and increased the incidence of vulval cancers (Vandegraaf 1976, Hawkins et al. 1981) led to a return to the recommendation of a medium-long tail, even in radically mulesed sheep.

Shedding of breech wool

Merino x Wiltshire horn (WH) sheep shed wool from the breech region, which greatly reduces the incidence of flystrike. For example for two groups of WH x Merino sheep the average annual incidence of strike was 3% and 9% compared to 32% and 48% for Merinos running with them (Tierney 1978). Rathie et al. (1994) report the results from further backcrosses in which increasing the proportion of WH also reduced the percentage struck. Over four years in ½ Merino, ⅝ Merino and ¾ Merinos the mean annual incidence of strike was 8.5%, 17.2% and 50.4% respectively. Both Tierney (1978) and Rathie et al. (1994) state that crutching and mulesing is not necessary in Merino x WH sheep. In New Zealand, Litherland et al. (1992) recorded the strike incidences of 33%, 10%, 0% and 10% over 6 months in Merino, Romney, feral sheep of Merino origin and Wiltshires respectively. The Wiltshires had the lowest dag scores while the feral sheep had a dag score consistently lower than the Romney and Merino breeds. All of the strikes in Wiltshires were body strikes associated with *Dermatophilus congolensis* infection rather than breech strikes.

Crossing with WH also markedly reduced fleece weight and increased fibre diameter (Rathie et al. 1994). However, these authors note that considerable variation was present in degree of shedding in all of the WH x Merino crosses and that it was doubtless amenable to change by selection. Although Wiltshires shed breech wool, they also have larger bare perineal areas than Merinos (Scobie et al. 2002), which probably also contributes to enhanced breech strike resistance.

Scouring and dag formation

The role of faecal staining in predisposing to breech strike is well established. The reasons for fluid faeces and dag formation have been reviewed by Waghorn et al. (1999) and Reid and Cottle (1999) investigated factors involved in adhesion of dags to the wool. Scouring or semi-fluid faeces can be caused by factors including helminth infestation, helminth larval challenge, fungal endophytes, nutritional factors such as type, quality, moisture content and level of intake of feed, rapid changes in diet and viral, bacterial or other parasitic disease. Waghorn et al. (1999) note that free pellets are characteristic of healthy sheep and that if sheep produced free pellets at all times wool staining and dag formation would not occur. With increased use of improved pastures and higher stocking rates, scouring and dag formation have increased in importance as precursors to breechstrike. Leathwick and Atkinson (1995) in New Zealand reported a correlation of 0.97 between dagginess and the incidence of strike.

The suppression of helminth infection by anthelmintic treatment or management practices can reduce the prevalence of scouring and subsequent strike. An association between drenching, reduced faecal egg count (FEC) and lower flystrike incidence was demonstrated as early as the 1950s in Britain (Leiper 1961). In Australia, drenching reduced the percent of radically mulesed Merinos with soiled breeches from 55.5% to 20% and incidence of breech strike from 50% to 23% (Morley et al. 1976). Similar results were reported by Watts et al. (1978) who showed that drenching ewes reduced the incidence of faecal soiling from 38% to 8% and the incidence of strike from 19% to 4% and from 34% to 6 % in two consecutive years. In New Zealand, grazing pastures rich in condensed tannins has been shown to reduce the incidence of breech strike (reviewed by Leathwick and Heath 2001). In trials on commercial farms lambs grazed on permanent pastures (largely ryegrass/white clover) became more daggy and were five times more likely to be struck than lambs grazed on condensed tannin-containing forage. Reduction in scouring probably results at least in part from lower worm burdens, but there may also be a direct effect of condensed tannins (Leathwick and Heath 2001).

Differences among sheep in resistance to helminth parasites and scouring *per se* are now well established (Eady et al. 1996, Greef et al. 1999, Morris et al. 2000) and selection for sheep that have lower worm burdens or are more resistant to scouring present potential additional methods of genetically increasing resistance to breech strike.

Immunological resistance to blowfly larvae

L. cuprina antigens invoke a range of inflammatory and immune responses in sheep (Sandeman et al. 1985, Bowles et al. 1987, 1992, Seaton et al. 1992). Although multiple repeated infections elicited a protective response manifest by slight reductions in larval growth and survival this response was weak and poorly sustained and probably of little practical consequence (Sandeman et al. 1986). Nevertheless, vaccination with blowfly antigens can confer a degree of protection against larval invasion and survival (Bowles et al. 1996, East et al. 1993). Differences have been demonstrated between resistant and susceptible sheep in their response to direct challenge with blowfly larvae and to *L. cuprina* excretory/secretory products. Omeara et al. (1992) found a greater wheal response to blowfly excretory/secretory antigens in sheep selected for bodystrike resistance although Colditz et al. (1992) found that plasma leakage in response to general inflammatory mediators, in particular activated complement, was greater in susceptible animals. Histological studies indicated higher numbers of mast cells in the skin of more resistant sheep (Colditz et al. 1994), consistent with a stronger inflammatory response. Inflammatory response to excretory/secretory antigens has been suggested as the basis for a test to select for resistance to fleece rot and bodystrike (Raadsma et al. 1992). However, there was no significant difference between resistant and susceptible sheep in the establishment and growth of larvae in either the study of Omeara et al. (1992) or Colditz et al. (1996). Studies to further investigate the extent of differences amongst sheep in their response to challenge by blowfly larvae are currently in progress (Colditz 2004).

Other rear end abnormalities

Waghorn et al. (1999) note tail length and conformation and anatomy of the anus and surrounding regions as one of the factors determining a sheep's propensity to dagginess and Beveridge (1935) discusses the part played by vulval morphology in urine staining. Malformations of the vulva and anus, whether genetically determined or caused by physical factors such as dog bites, cuts during shearing, crutching or at mulesing, can result in persistent wool staining and increase in flystrike susceptibility. Sheep consistently struck because of such abnormalities are usually culled by sheep owners, but the opportunity for significant improvements from more structured breeding programs appears small.

Potential for genetic modification

Breech wrinkle

Seddon et al. (1931) showed that resistance to breech strike was genetically determined and could be improved by judicious selection of breeding stock. Results from their studies, which probably represents one of the earliest studies of breeding for resistance to flystrike are shown in Table 4.

Table 4: Proportion of lambs of different susceptibility class resulting from mating ewes of class A, B, C to rams of the same type (Belschner and Mulhearn 1931)

Ram and ewe type	Percent of lambs in each class		
	A	**B**	**C**
A	55	43	2
B	16	84	14
C	2	21	21

Most estimates of heritability of wrinkle score have been made using the photographic standards of Carter (1943) or Turner et al. (1953). Each series contains a set of photographs for the neck, sides and breech. Where sheep have been mulesed, the breech score is omitted. Wrinkle scores are assigned separately for the different body regions and averaged to give the final score. Table 5 summarises estimates of heritability for wrinkle score.

Table 5: Estimates of the heritability of wrinkle score

Reference	Sheep	Measure	Value
Beattie 1962	Medium Peppin	Neck Side	0.26 0.30
Young, Turner and Dolling 1960	Medium Peppin Rams 10-12 mths Ewes 15-16mth Rams 15-16 mth	Overall, not including breech?	 0.46 0.35 0.48
Morley 1953 Morley 1955	Medium Peppin	Overall, not including breech?	0.5 0.42
Gregory 1982	SA Merino Ram Ewe Ram Ewe	Overall, not including breech?	0.26 0.34 0.46 0.42
Brown and Turner 1968	Merino	Overall	0.38
Lewer et al. 1995	Merino ewes	Neck Breech	0.27 0.19
McMahon 1943	Romney	Overall	0.10
Shelton et al. 1954	Mixed breeds	Body	0.20

There are few estimates specifically for the heritability of breech fold score, probably because most flocks on experimental stations are mulesed. Lewer et al. (1995) estimated a value of 0.19 and Raadsma and Rogan (1987) cite a value of 0.4-0.5 with the source given as “McGuirk unpublished”. However, wrinkle scores for neck and breech are highly genetically correlated (1.00, Jackson and James 1970; 0.91, Lewer et al. 1995) and the genetic correlation between body and breech wrinkle is very high in one study and moderate to high in the other (0.99, Jackson and James 1970; 0.50, Lewer et al. 1995). Thus all indications are that the heritability of breech wrinkle is moderate to high and that substantial gains could be made by selection.

However, even in the early days of selecting for plain breeches concerns were expressed about the level of flystrike protection likely to be achieved. The Joint Blowfly Committee (1933) cautioned that even one small wrinkle may allow the development of a susceptible area and Johnstone and Graham (1941) noted that opponents of the mules operation often argued against its use on the grounds that even plain-bodied animals could have relatively high incidences of strike. Johnstone and Graham (1941) separated the plain bodied sheep from a mob, dividing the remaining wrinkly animals to two groups, one in which sheep were mulesed (modified mules) and one in which sheep were left unmulesed. Only 1 percent of the mulesed wrinkly sheep became struck compared to 8.6% of the unmulesed plain breeched sheep and 31% of the unmulesed wrinkly sheep. They closely inspected many of the struck plain breeched animals and could find no evidence any breech folds. In addition, the effect of crutching in controlling strike lasted longer in the mulesed wrinkly sheep than in the plain breeched group. Similarly, Moule (1948) found that the incidence of strike was 98% and 19% in unmulesed wrinkly and plain breeched sheep respectively, compared to 4% in both mulesed wrinkly and mulesed plain breeched sheep. Morley et al. (1949) reported that 72% and 24% of unmulesed plain breeched sheep (class A) were struck in spring and autumn respectively compared to only 1.1 and 1.0 % of mulesed and tail stripped animals with class A, B and C breeches. Thus it appears that protection provided by selecting for plainer breeches is not comparable to that provided by mulesing and Reid and Jones (1976) concluded that: "Despite increased interest in breeding easy care Merinos it appears that selection could never avoid the need to inhibit breech wool growth by some artificial means".

Selection against skin wrinkle has now been practised over many years to improve flystrike resistance, but also because a high degree of skin wrinkle is associated with reduced fertility and other management difficulties (Dun 1964). Most modern day Merinos are relatively plain bodied anyway and, although individual animals with high wrinkle scores should be culled, it is questionable whether further intense selection against breech wrinkle in relatively plain bodies lines would bring significant reductions in flystrike susceptibility.

Bare area

There are significant differences between breeds in bare area dimensions and Scobie et al. (1999) indicate that both the East Fresian and Wiltshire Horn breeds have relatively large natural bare areas. Furthermore there are particular individual sheep with "usefully bare breeches" found within some breeds, notably the Border Leicester, Poll Dorset, East Friesian and Texel breeds (Scobie et al. 1997, 1999). Thus the possibility exists that genes from other breeds could be introduced to increase bare area dimensions in Merinos.

The only estimates of the heritability of bare area in Merinos appears to be those of James and Lewer (unpublished), although data that will enable further estimates is currently being collected in Western Australia (Karlsson et al. 2001). Theses estimates suggest that bare area is an inherited trait in Merinos with low to moderate heritability (Table 6) and preliminary indications are that heritability may increase with age. This could be because as the animals grow, skin surface area to body weight ratio changes and bare area measurements are less confounded by growth factors or differences in growth stage. In addition estimates at later ages are likely to be more reliable than those at birth because of the difficulty of getting accurate measurements in newborn lambs. The apparently moderate to high heritability of post mulesing bare area is of interest. This could be a reflection of heritability increasing with age or that other heritable factors influence the outcome produced by mulesing. A further possibility is that this is a sampling effect due to the fact that most of the animals included in the post mulesing analysis were females as most of the males had been sold. The morphology of the rear end is different in males and females and it could be that heritability differs between the sexes. Future analyses of heritability in the two sex groups at younger ages should help to clarify this.

Thus it should be possible to increase the area of bare perineal skin by selection from within a population of animals. However, the relative magnitude of the difference in size of the bare area between mulesed and unmulesed sheep suggests that it would take many generations to achieve a bare area comparable to that produced my mulesing. Differences in the natural pattern of wool growth on and around the tail will also influence breech strike susceptibility, particularly in areas where scouring is prevalent, but to date the extent of differences between sheep and the potential for genetic change has received little consideration.

Table 6: Heritability of bare area dimensions (James and Lewer unpublished)

Birth	**Heritability (standard error)**
Width at anus	0.244 (0.100)
Width at vulva	0.068 (0.064)
Length	0.070 (0.064)
Total area	0.157 (0.083)
Area adjusted for weight	0.083 (0.067)
Marking	
Width at anus	0.204 (0.092)
Width at vulva	0.155 (0.082)
Length	0.193 (0.090)
Total area	0.153 (0.082)
Area adjusted for weight	0.232 (0.098)
Post mulesing	
Width at anus	0.450 (0.168)
Width at vulva	0.250 (0.131)
Length	N.A.
Total area	0.397 (0.159)
Area adjusted for weight	0.376 (0.155)

There has also been a suggestion of some phenotypes of Merinos that do not grow wool in the breech and pizzle regions (Neil Smith pers com). It is suggested that in addition to not requiring mulesing these animals do not require crutching or ringing. These sheep appear to fall outside of the range of normal of Merino phenotypes and may provide a means of rapidly increasing the area of bare perineal skin without the need to introduce genes from other breeds. Further research is required to assess the relative incidence of staining and breech strike in these animals, the mode of inheritance and consequences of selection for this trait and to identify any further sources of individuals with 'bare breech' phenotypes from within the Merino population.

Tail length

All domestic breeds of sheep presently raised in Australia have long tails. However, there are many breeds around the world that are naturally short tailed and many reports in the literature of the occurrence of short tail animals in long tail breeds. Lydekker (1913) classified sheep breeds into groups based on tail length and morphology. He points out that most wild sheep have short tails and suggests that length of tail is an index of degree of domestication. Shelton (1977) supports this view indicating that Mouflon sheep, the presumed ancestors of present day domestic breeds, have short tails.

Tail length appears to be inherited two major ways, as a multigenic or quantitative trait, which studies to date suggest is the major mode of inheritance in most short tail breeds, and through one or a few genes of major effect, which appears to be the major mode in extreme short tail phenotypes occasionally found in long breeds.

Inheritance in short tail breeds

The inheritance of tail length in crossbred Finn sheep, which are naturally short tailed, was studied by Branford-Oltenacu and Boylan (1974). Finn sheep mated to long tailed sheep of Suffolk, Targhee and Minnesota 100 breeds produced progeny that had tail lengths that were normally distributed with means midway in length between the Finnish Landrace and the long tailed breeds. There was no overlap between the distributions of tail length in the Finns and standard breeds. F2 progeny had similar mean and variance of lengths as the F1 generation whereas the backcrosses had tail length that tended to that of either the Finn or the standard breed, depending on the sire. They concluded that tail length was a multigenic trait but that there was some degree of dominance for the short tail genes.

Shelton (1977) mated short tail Mouflon and long tail Rambouillet sheep and found that the number of coccygeal vertebrae in the F1 progeny was approximately midway between that of the two parent breeds. Sheep with some Mouflon breeding had reduced tail lengths with the degree of reduction closely related to the amount of Mouflon infusion. Scobie and O'Connell (2002) mated sires of various tail lengths generated from various crosses of Finnish Landrace and Cheviot sheep to ewes that were either purebred Finn (shortest tail length), Cheviot (longest) or Finn x Cheviot (midway between the two parent breeds). They also concluded that tail lengths in the progeny were best explained by additive effects of tail length of the sire and tail length of the dam. Plotting tail length of the lambs by percentage of Finnish Landrace genes gave an approximately straight line.

Thus indications are that tail length is normally a quantitative trait in both short and long tail breeds. Estimates for the heritability of tail length in sheep have been made and are summarised in Table 7. With the exception of one estimate, these values suggest that tail length is a moderately to highly heritable trait that could be improved rapidly by selection. Phenotypic correlations between tail length and production characters including 120 day weight, weaning condition score, wool cover score, greasy and clean wool weight and staple length in Rambouillet and Rambouillet x Mouflon sheep are given by Shelton (1977). Tail length had low positive correlations with wool cover score and staple length in the Rambouillet sheep whereas, as would be expected on the basis of differences in production traits between the two breeds, the correlations were stronger in the Mouflon x Rambouillet cross sheep and there were also significant positive correlations between tail length and greasy and clean fleece weight.

Even though it is clear that tail length is strongly inherited and preliminary estimates suggest that there are no serious unfavourable correlations with production characters, Shelton (1977) notes that it is not possible to say if selection within the population of domestic sheep would permit elimination of the necessity for tail docking or simply cause the mean to approach minimum values for the breed involved. In addition, Scobie and O'Connell (2001) note that New Zealand shepherds are committed to docking even short tail Finn sheep, although whether this is required to control staining and flystrike, conducted to assist ease of shearing or simply traditional practice is unclear. They also make the important point that from the perspective of flystrike control a short tail length will not be the complete solution - it will also be desirable that the distribution of wool on the tail does not make it susceptible to staining with urine and faeces.

Table 7: Estimates for the heritability of tail length in sheep

Breed	Estimate	Mean tail length	Reference
Finn	0.77 (0.42) (sires) -0.12 (0.45) (dams)	7.85 (0.06)	Branford-Oltenacu and Boylan (1974)
Combined standard breeds	0.50 (0.24) (sires) 0.84 (0.41) (dams)	17.32 (0.11)	Branford-Oltenacu and Boylan (1974)
Rambouillet	0.39		Shelton 1977
Part Mouflon	0.71		Shelton 1977
Finn x Cheviot	0.82 (0.10)		Scobie and O'Connell (2002)
Fat Tail (Menz and Horro breeds)	0.37 (0.15)		Ermias and Rege (2003)

Genes of major effect

Many instances of lambs born without tails (anury) or with shortened tails (brachyury) have been reported in the predominantly long-tailed breeds. Of 602 replies to a survey questionnaire on congenital defects in lambs in Western Australia, 11.1% reported occurrence of lambs born with a shortened tail and 10.1% lambs with no tail (Dennis 1965, 1974). Of 4,417 lambs examined by Dennis (1972), 0.4% had shortened tails (2-5 cm in length) and 0.1% had no tails. Most of these tail abnormalities were associated with other more serious bodily defects, commonly musculo-skeletal defects and imperforate anus. Ercanbrack and Price (1971) and Ercanbrack and Knight (1978) reported frequencies of 0.01% and 0.02% of lambs born with short tails in the Rambouillet and Columbia (long tail dual purpose meat and wool breed) breeds respectively in Idaho. They also found a significant difference in frequency of the trait in inbred lines and concluded that there was a measure of genetic control for this defect.

A breed called the No Tail was developed over 50 years at the South Dakota State University in the United States. Its history is described by Wilson (1940) and Jordan (1952). Fat rumped sheep with tails completely absent were imported from Siberia in 1913. They were mated to Shropshire, Hampshire and Cheviot ewes with the ultimate aim of developing a tailless breed with good mutton and wool qualities. Much discouragement accompanied the early crosses as all of the offspring had tails. It was not until the fifth generation that a tailless lamb was born. In 1926 Rambouillet ewes were introduced in an effort to improve fleece quality. Although the exact mode of inheritance was not clarified in these animals, the trait appeared to be recessive. Jordan concludes that it was "not a simple recessive and multiple factors with modifying effects and possibly complementary factors were involved".

As taillessness was a multiple factor trait it did not become fixed in the flock. Near the end of the breeding program after approximately 50 years of breeding, 40% of the lambs were tailless at birth, another 20% had tails of 2.5 cm or less and the remaining 40% had tails that ranged up to 15cm in length. Where tails were present they were usually crooked. Heritability of tail length in this flock was estimated as 0.46 (Mr JM Thompson, pers. com. 1988). When No Tail rams were mated to long tailed ewes, all of the resulting progeny had normal length tails. At least four back crosses to No Tail rams were required to produce a lamb drop with significant numbers of short tail progeny. However, as has been the case in a number of studies with short tail animals, this trait appeared to be associated with deleterious effect named 'sidewheeler' which caused paralysis of the hindquarters. While some affected lambs were able to move about and grow normally, the majority starved to death. The breeding flock was eventually sold in 1964 and it appears that no attempts were made to maintain the tailless trait (Mr JM Thompson, pers. com. 1988).

Carter (1976) reported that taillessness in a Romney flock was the result of a simple dominant genetic factor that caused variable hypoplasia of the coccygeal vertebrae. However, no homozygous sires were identified in progeny tests and it was found that the gene caused embryonic death approximately 3 to 4 weeks after fertilisation when present in the homozygous state. The author suggested that some of the congenital abnormalities observed appeared akin to spina bifida.

In the 1980s the Australian Merino Society carried out a project looking for sheep with no tails or four functional teats (AMS News 1987). Murphy (1988) reported the results of mating of three phenotypically short tail Merino rams and a short tail ewe collected from Western Australian flocks. No lambs from these matings were born with short tails.

James et al. (1990, 1991) reported studies of the inheritance of a short tail phenotype first noted in a South Australian Merino flock. Mr Don Gare of Mt Glen View at Jamestown in South Australia first noted short tail animals in 1956 and had continued to mate short tail rams each year since that time. Experimental matings of short tail rams to ewes with no history of the short tail trait in two years produced 12.6% and 4% of short tailed lambs. There appeared to be a bi-modal distribution of tail lengths amongst the progeny and they concluded that inheritance was possibly determined by a small number of genes with directional dominance or a small number of interacting genes. Short tail rams mated to F1 ewes in the second year produced 15% of lambs classified as short tailed. In the backcross to 60 F1 females, scanning indicated that all but one became pregnant, suggesting no effect on fertility. However 27 lambs died between birth and marking and 7 of these had rear end abnormalities, most commonly blind or restricted anus or aberrant urogenital tract. In addition, the short tails in these animals were generally not straight, but bent either laterally or dorso-ventrally and generally appeared to have little muscle tone, suggesting that the sheep could not lift them out of the way when defaecating or urinating. This often predisposed the animals to increased levels of urine or faecal staining. Although subsequent matings increased the proportion of short tailed progeny, the number lambs born dead, or with rear end or spinal defects also increased, suggesting little potential for producing a practically acceptable line of short tail animals using the genes from this bloodline.

Thus where short tail animals have arisen in otherwise long tail breeds the short tail phenotype has almost invariably been associated with other deleterious effects. This has also appears to have been so with other domesticated animals. For example, taillessness is a lethal anomaly in mice and dogs (Hamori 1983) and taillessness in Manx cats and short tail cattle dogs is also often associated with rear end abnormalities or higher than normal mortalities at birth (Deforest and Basrur 1979). However, the possibility of using genes of major effect already present in the Merino population should not be completely discounted. Rather, any future studies with unique short tail phenotypes should be structured to allow the early identification of any deleterious effects. Regardless of which approach is taken to breeding short tail animals, the pattern of wool coverage on and near the tail would need to be considered to ensure that the likelihood of staining and strike is not increased.

Shedding of breech wool

Breeding sheep that shed wool in the perineal region offers a possible way of addressing staining of both the breech wool and the wool that hangs down from above the tail. There is no suggestion that sheep that naturally shed breech wool exist within the Merino breed, suggesting that the trait would have to be introduced from other breeds. Wiltshire horns, the main breed present within Australia in which shedding occurs, have markedly lower wool cuts and coarser wool than Merinos and crossbreeding with these breeds has resulted in markedly lower wool receipts (Rathie et al. 1994). Backcrossing to Merinos to improve fleece value reduced fleece shedding and increased breech strike susceptibility. There appears to have been no investigation of the mode of inheritance of the shedding trait and the degree to which it could be incorporated into Merinos without compromising production attributes is uncertain.

Scouring and dag formation

Changing breech conformation and the pattern of wool cover on the perineum and near the tail is a potential way of genetically reducing susceptibility to strike in scouring sheep, but there is also the possibility of genetically reducing propensity to scouring. It is clear that reducing helminth numbers can have significant effects in lowering flystrike incidence and it is now well established that susceptibility to internal parasitism is under genetic influence (Eady et al. 1996, Woolaston and Baker 1996, Morris et al. 2000). Appropriate selection strategies can markedly reduce the level of worm burdens (Greef et al. 1999, Morris et al. 2000) and selection programs to increase resistance to helminth parasites, such as Nemesis in Australia and WormFec in New Zealand have been widely promoted to sheep owners (McEwan et al. 1995, Eady et al. 1997).

However, selecting for resistance has not led to an associated decrease in scouring or dag formation in most instances. In fact more often the reverse has been true. In New Zealand Morris et al. (1997) reported that lambs selected for low FEC had 41% more dags than lambs selected for high FEC and Bissett et al. (1997) reported that lambs selected for resistance to worms had more dags and looser faeces than susceptible sheep. In Merinos, Pocock et al. (1995) reported a significant negative phenotypic association between dag score and FEC in a commercial Merino flock and estimates for the genetic correlation between FEC and scouring traits for Merinos, summarised by Larsen et al. (1999), range from –0.06 to –0.67, also suggesting that selection for resistance could lead to an increase in faecal staining. However, it should be noted that although there was a negative genetic correlation between FEC and scouring in early analyses from the Rylington Merino selection line (Karlsson and Greeff 1996), more recent results indicate a low positive correlation, suggesting that an unfavourable relationship may not apply in all situations (Greeff et al. 1999). In addition, both Greeff and Karlsson (1999) from studies with an unselected hogget flock and Woolaston and Ward (1999) from an analysis of the CSIRO Haemonchus selection lines concluded that selection for low FEC should not result in a significant increase in scouring.

A syndrome variously referred to as hypersensitive scouring, nutritional scours or winter scours related to hypersensitive response to the intake of worm larvae is now recognised. Its pathogenesis and control is reviewed by Larsen et al. (1999). Sheep vary in their susceptibility to hypersensitive scouring with very susceptible sheep scouring in response to ingestion of even low numbers of larvae. Possible immunological bases for this response are discussed by Douch et al. (1995), Larsen et al. (1999) and Shaw et al. (1999). From a survey of the causes of dagginess in sheep in New Zealand, Wesselink et al. (1995) concluded that larval challenge appeared to be a more important cause of scouring than worm burden per se.

There is now a significant bank of evidence indicating that susceptibility to scouring is genetically determined. In New Zealand estimates of the heritability of dag score in flocks of different breeds varied from 0.13 to 0.60 with a mean value of 0.31 (Harvey et al. 1984). More recently, Baker et al. (1991) reported estimates for the heritability of dag score that ranged from 0.25 to 0.54 and Shaw et al. (1999) estimated heritabilities of 0.40 for dag score and 0.16 for faecal consistency in Romney sheep.

In Australia, Larsen (1995) reported significant and repeatable differences among Merino bloodlines, suggesting that susceptibility to dag score also had a strong genetic component in this breed. Subsequently, Karlsson and Greef (1996) estimated heritabilities of faecal consistency score (scored from 1 = hard pellets to 5 = fluid faeces/scouring) of 0.23 (±0.7) at 3 months of age and 0.17 (±0.06) at 10 months and heritability of dag score as 0.08 (±0.04) at 8 months of age. Greeff and Karlsson (1997) estimated heritability of faecal consistency score as 0.37 (±0.05) at weaning and 0.38 (±0.06) in hoggets. Estimates from Greeff and Karlsson (1999) and Woolaston and Ward (1999) were somewhat lower, at 0.13 (±) 0.03) and 0.09 (±0.07) respectively, but still suggested that reductions in faecal staining could be made by selection.

It therefore appears that selecting against propensity to scouring and dag formation should lead to a reduction in susceptibility to breech strike and could be considered as part of a genetic approach to reducing breech strike susceptibility. Selecting against dags may be particularly important where selection for low FEC is practiced to prevent any associated increase in breech strike susceptibility. Repeatability estimates suggest that selection based on dag weight may give more rapid gains than using dag score or faecal consistency (Larsen et al. 1999).

Immunological resistance to blowfly larvae

Resistance to fleece rot and body strike is known to be heritable with estimates of heritability generally between 0.2 and 0.4 when estimated on an incidence independent scale (McGuirk and Atkins 1984, Raadsma 1991). Improvements in body strike resistance have been achieved by selecting against occurrence of body strike and the major predisposing condition, fleece rot (Mortimer et al. 1998). A number of wool characteristics, in particular wool colour (James et al. 1987, Raadsma and Wilkinson 1990), coefficient of variation of fibre diameter and associated fleece structure characters (James et al. 1987, Raadsma 1993) and wax content have been shown to be associated with fleece rot resistance and may be suitable indirect selection criteria (Mortimer 2001). In addition, studies on sheep selected for and against fleece rot and body strike resistance at Trangie research centre over more than 20 years have indicated the potential involvement of immunological characters in resistance to fleece rot. Antibody responses to *P. aeruginosa* antigens were generally greater in resistant sheep (Chin and Watts 1991, Gogolowski et al. 1996) and Burrell (1985) has shown that immunisation, which induces higher anti-*Pseudomonas* antibody levels, can confer resistance against fleece rot. Even though these results suggest some involvement of immunological response in fleece rot resistance, Colditz et al. (2001) conclude that taken overall, results from the studies conducted on the Trangie resistant and susceptible sheep suggest that it probably plays a secondary role to that of fleece characteristics. The implications of these findings for resistance to breech strike are unclear. *Pseudomonas* and a number of other bacteria are known to proliferate in the breeches of sheep with extensive urine wetting (Bull 1931) but the importance of bacterial growth to the initiation and development of breech strikes is uncertain.

O'Meara et al. (1995) found no difference between resistant and susceptible sheep in the establishment of strikes or the growth of larvae where sheep were challenged with larval implants, although it was noted that the more resistant animals had greater exudation of serum proteins onto the skin surface in the first 12 hours after infestation. More recently Colditz et al. (2004) have estimated heritability of 0.21 and 0.29 for mean larval weight and total larval weight respectively in sheep given a standard challenge with 50 first instar larvae at four sites on each sheep. However, the proportion of larvae that survived was not heritable (h^2 = 0.01). Although there appears to be heritable variation in the rate at which larvae develop, clarifications of the implications of this variability to resistance to flystrike, and more particularly resistance to breech strike, will await the results of future studies.

Conclusion

A genetic solution to breech strike control is attractive as it is potentially permanent, cumulative, does not involve increased use of chemicals and may ultimately reduce labour inputs. Although there appears to be significant opportunity to reduce the susceptibility of Merinos to breech strike by genetic means, much of the information required for a full assessment is not presently available. Selection for increased bare skin in the breech or short tails has not been attempted within the normal Merino population and offers the possibility of modification without the complication of introducing undesirable non-Merino genes. However, whether sufficient variation is present to make practical improvements in breech strike resistance or reductions in tail length is uncertain. Crossing with other breeds may be the most rapid means of increasing breech strike resistance and reducing tail length, but is also likely to compromise many of the desirable production attributes of Merinos. Identification of animals with extreme phenotypes from within the Merino population would seem to be the most convenient and achievable way to proceed if suitable animals can be identified, particularly if the required traits are determined by genes of major effect.

It seems unlikely that breeding alone will be able to confer the degree of protection provided by surgical mulesing and tail docking. Breech strike control generally consists of an integrated approach which may include mulesing, tail docking, crutching, control of scouring through nutritional management and good internal parasite control, strategic shearing, preventative application of insecticides and treatment of struck sheep. Any breeding program which seeks to replace surgical mulesing and tail docking will need to make sheep sufficiently resistant that the increased requirement for other strike management procedures remains within practically acceptable bounds. Ultimately, the desirability of a genetic approach will be strongly determined by market imperatives and it is likely that there will need to be a trade off between the requirement for alternatives to surgical flystrike controls and other production goals.

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