

A review of mulesing and other methods to control flystrike (cutaneous myiasis) in sheep

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Abstract

Flystrike (cutaneous myiasis) in sheep has the potential to have a major impact on the welfare of significant numbers of sheep worldwide, but particularly in Australia. The main control method used in Australia, the mulesing operation to remove folds of skin from the hindquarters of the sheep, is effective in controlling the disease, but will be terminated from 2010 as a result of concerns that the operation itself has too great a negative impact on sheep welfare. Alternative treatment methods are considered, and it is proposed that they need to be appraised for each farm separately, based on the conditions prevailing and the potential to apply the different treatments. Sheep are predisposed to flystrike if their fleece is wet or contaminated with faeces or urine. Monitoring and awareness of the weather conditions will enable farmers to strategically treat their sheep with insecticides, or to observe them and treat affected animals more regularly. Frequent removal of wool by crutching, dagging and shearing will aid wool desiccation after rainfall and decrease the likelihood of fleece contamination with excreta. Some control of diarrhoea can be achieved by good grazing management and treatment of diseases that predispose sheep to the disorder. Reducing fly populations can be achieved by the use of traps, and parasitoid wasps also offer some promise. Alternative methods of removing wool and wrinkles from the hindquarters of sheep, including the topical application of quarternary ammonium compounds, phenols, caustic soda or plastic clips, have yet to be proven to be effective, without severely impacting on the welfare of the animal as well as compromising operator safety. In the long term, the breeding of sheep without wrinkles or wool on their hindquarters offers the most likely method of control, although a small proportion of sheep are affected on other parts of their body.

Keywords: animal welfare, cutaneous myiasis, flystrike, *Lucilia cuprina*, mulesing, sheep

Introduction

Flystrike is a serious problem in all the major sheep-producing countries of the world but, in particular, Australia, the United Kingdom and New Zealand. The problem is most acute in Australia, where the risk of strike is high due to the combination of susceptible sheep, large extensively-managed flocks, which are not inspected regularly, and warm climatic conditions. The most common method of control is the mulesing operation, whereby wrinkles around the hindquarters of sheep are surgically removed, usually without the application of anaesthetic. The operation is not commonly used in other sheep farming countries, and is illegal in most, although there is evidence to suggest that it is used on a small scale in New Zealand (Heath 1994). In 2005, following a campaign by activist organisations, the Australian wool industry representative body agreed to terminate the practice in Australia by the end of 2010, which suggests that a careful evaluation of alternative control methods is necessary. It is conceivable that there will be no single, alternative control method as effective as mulesing on all farms, but individual farms will have to devise their strategy according to their own specific

conditions and the possibilities to implement different control methods. This paper reviews the effectiveness and welfare impact of controlling flystrike by the mulesing operation and other control methods.

The pathology and epidemiology of flystrike in sheep

Flystrike (cutaneous myiasis) occurs after gravid female blowflies are attracted to lay their eggs in the wool of sheep by olfactory cues. Occasionally it occurs in the feet of goats and in cattle and dogs (Heath & Bishop 2006). The resultant damage or 'strike' is mainly due to the mechanical and chemical effects of the feeding activity of the larvae. It causes a reduced staple length following the stress response, which is evidenced by elevated cortisol, interleukin-6, serum amyloid A and haptoglobin (Colditz *et al* 2005). In addition, struck sheep often present with a moderate fever and depressed feed intake (Colditz *et al* 2005).

Flystrike was seldom a concern in Australian sheep farming between the arrival of the first migrants with their sheep in 1788 and the late 19th/early 20th Century. At this time, sheep were plain breeched (without wrinkles and wool on their

breeches), closely shepherded, pastures were unimproved and worm burdens were low due to the low stocking densities, with diarrhoea consequently relatively rare. The introduction of ten Vermont Merino rams into New South Wales and Tasmania in 1883, which had a pair of folds running vertically along each side of the perineal region, produced increased wool yields, but a shorter staple and increased yellowing. This, together with pasture improvement and the introduction of a major new fly species causing strike, *Lucilia cuprina* Wiedemann (Diptera: Calliphoridae), produced a need to protect sheep from flystrike due to the potential for high losses. *L. cuprina* spread throughout Australia in the early 20th Century, probably arriving from Africa, and it did not enter Tasmania until the 1950s and New Zealand in the mid 1970s, although the DNA evidence suggests multiple introductions into New Zealand (Heath 1994; Gleeson & Sarre 1997). In Australia, there has been no evident change in the principal fly species, *L. cuprina*, responsible for strike since the early assessments of the 1930s (Joint Blowfly Committee 1933; Belschner & Seddon 1937). In New Zealand, the major species involved was reported as *Calliphora stygia* in 1841, *Lucilia sericata* in 1872 and *Chrysomya rufifacies* in 1911 (Heath 1994). More recently, with the advent of *L. cuprina* into New Zealand, it has been estimated that about 4% of New Zealand's 50 million sheep are affected by overt strikes (ones that are detected), and probably a similar proportion by covert strikes that remain undetected (Bishop *et al* 1996).

Most flystrike occurs in the breech region of sheep (Watts *et al* 1979; Heath & Bishop 2006), and can be divided into crutch strike (from the tail base to the border of the udder or scrotum) and tail strike, usually around the stump or sides of the tail (James 2006). The crutch is the most favoured place to lay eggs when conditions are dry (Wardhaugh *et al* 2001), and in wet conditions body strike (strikes to the back, withers or shoulder) is more likely to be significant. Other areas that are less commonly struck include the flank, poll, pizzle, udder, foot and scrotum (Heath & Bishop 2006). Lambs are less commonly struck on the flank, compared with older sheep (Heath & Bishop 2006). Strikes tend to increase in likelihood following cuts during shearing, crutching or mulesing (Wardhaugh *et al* 2001). Strike is often covert initially, only becoming overt when there has been considerable damage (Bishop *et al* 1996). For effective strikes, the flies require a sufficient base population to successfully breed on sheep. Small egg clusters appear to desiccate, in the same way that a single egg is unlikely to generate an infestation, whereas large egg masses will almost invariably produce a struck sheep (Anderson *et al* 1988).

Mulesing

The mulesing operation was developed in 1931 by Mr JHW Mules, a South Australian sheep farmer. Before this time, attempts to control flystrike were by regular inspection, at least once a week, and crutching. Treatment was by the application of chemicals to the infected site, usually arsenic, copper, boron or phenols (Morley & Johnstone 1983). At this time, detailed consideration was being given to the breeding

of plain-bodied sheep (without wrinkles) as an alternative means of reducing susceptibility to flystrike, and this was later shown to result in negligible loss of wool production and even some improvements in reproductive performance (Morley & Johnstone 1983). However, as the operation that Mules pioneered both effectively and rapidly reduced the risk of blowfly strike, this method gained more favour.

The procedure involves the removal of loose skin, in order to stretch and permanently enlarge the bare area on the breech and tail. The operation originally described by Mules involved clamping the skin with Burdizzo pincers and cutting off the surplus skin with a knife. At the time the clamp was presumed to paralyse nerve endings, reducing the pain of the operation (Morley & Johnstone 1983). Some South Australian graziers adopted the technique but many were repelled by its apparent cruelty. Early trials showed some benefit of mulesing in reducing flystrike, but it was not nearly as successful as the modified techniques adopted later. Repeat treatment was often necessary. The Burdizzo was replaced in the 1930s by Rolcut secateurs then, in the early 1940s, dagging shears were used and a larger area was made bare (the modified Mules operation). In the late 1940s, severe risk of strike was found to be best averted by a more extreme removal of skin, whereby the tail was cut short and skin removed over the tail and between the tail and crutch (known as a Radical Mules operation). A disadvantage of this technique was that it predisposed the sheep to cancer in the perineum region, with a prevalence of about 3% (Morley & Johnstone 1983); hence, it became recommended to leave some wool on the dorsal surface of the tail. A recent review of studies comparing the prevalence of flystrike in mulesed and unmulesed sheep demonstrated that the proportion of sheep being flystruck was uniformly low in mulesed sheep, but in unmulesed sheep the proportion varied from negligible levels to almost the entire flock, depending principally on the weather (Lee & Fisher 2007).

The Australian Wool Corporation engaged in a persuasive campaign to encourage producers to adopt the mulesing technique (Morley & Johnstone 1983). Blowfly schools were established and amongst the arguments used to persuade graziers to perform the operation were the observation that lambs went immediately to their mother to suckle after being mulesed (apparently indicating a limited behaviour response) and the far greater impact flystrike has on welfare compared to the operation. Clearly, the most persuasive argument was that following the development of a successful mulesing programme, the graziers could reduce the frequency of flock inspection, allowing them time to manage other aspects of their farming operations, such as checking pasture and water quality. Farmers in the State of Victoria were less keen than those in other States to use the operation because they believed it to be cruel, and this led to them being branded 'ill-informed and conservative' (Morley & Johnstone 1983).

An acute stress response to mulesing is detectable immediately after treatment, with responses in some spectra of electroencephalographic measurements indicating that mulesing is more stressful than shearing or other handling

in the first 15 minutes, post treatment (Jongman *et al* 2000). There are elevated blood cortisol and β -endorphin concentrations for about two days (Fell & Shutt 1989), with the levels reached indicating that mulesing and other surgical procedures have a greater impact than other potential stressors, including transport, shearing and movement with dogs (Shutt *et al* 1987; Fell & Shutt 1988). Although cortisol is still elevated at 24 h post-mulesing, β -endorphin concentrations have returned to a normal level by this point (Shutt *et al* 1987). Lomax *et al* (2008) demonstrated that topical administration of Trisulphen (an anaesthetic containing lignocaine, bupivacaine and adrenalin) accelerated wound healing, reduced pain-related behaviour and reduced wound sensitivity to touch. Paull *et al* (2007) recently investigated the effects of mulesing on stress and behavioural responses of lambs, and also the benefits of analgesic administration. They recorded cortisol and behavioural responses over a 24 and 12 h period, respectively, post-mulesing. Mulesing elevated cortisol substantially in the first six hours, and the cortisol response was still evident after 24 h. Similarly, the behavioural response to mulesing — increased standing, particularly in a hunched position, and reduced lying — was not only still evident at the end of recording, but the difference in the amount of time spent standing and lying between the mulesed and not mulesed treatments actually increased from the first to the last 4 h period for the mulesed treatment. The administration of most of the analgesics tested was ineffective at attenuating the effects of mulesing, although carprofen and a topical anaesthetic administered together successfully controlled the cortisol increase that occurred in the first six hours after treatment and the behavioural responses to mulesing were also largely eliminated. However, from 6–24 h, the cortisol concentrations in sheep mulesed, together with the administration of carprofen and topical anaesthetic, was greater than non-mulesed sheep and similar to the mulesed sheep without analgesic. Hence, it appears that although the most successful analgesic administration did eliminate the immediate effects of mulesing, it did not control the longer-term effects. More recently, Paull *et al* (2008a) have demonstrated that a combination of a long- and short-acting analgesic can provide more complete pain relief following the mulesing operation. However, Paull *et al* (2008b) found little benefit of providing two non-steroidal anti-inflammatory drugs, tolfenamic acid and meloxicam applied before or at the time of mulesing.

Other research has demonstrated that behaviour is severely affected by mulesing for about three or four days, with a hunched up posture, increased standing, less grazing and lying, cessation of play and other social interactions, apparent hypersensitivity to other stressors, such as the presence of insects, and an extreme fear of their handlers (Shutt *et al* 1987; Fell & Shutt 1989). The fear response is particularly exhibited at the first handling post-mulesing, with a major cortisol and β -endorphin surge, and it persists for several weeks in response to the presence of the person who had conducted the mulesing operation (Fell & Shutt 1989). Sheep have good memories of handling procedures

and, for this reason, it was recommended that if mulesing had to be performed that it was done by contractors rather than the regular handlers of the sheep (Fell & Shutt 1989).

The increase in stress hormones and changes in behaviour and live weight, post-mulesing and in response to flystrike, can be compared to determine whether there is any potential welfare benefit on the Australian sheep flock. Flystrike induces a cortisol increase of approximately 70 ng ml⁻¹, which will probably be maintained until it is detected and treated, on average about 10 days, whereas mulesing induces an increase in cortisol of 43 ng ml⁻¹ for 1.5 days (Lee & Fisher 2007). Giraud *et al* (2008) used a risk management approach to determine that the behavioural and physiological responses to mulesing were less overall than to flystrike for the Australian Merino flock. In the absence of mulesing, the welfare of sheep is best preserved by genetic selection and enhanced fly control. However, in addition to the immediate stress responses, there are other effects of mulesing practice or use of alternatives that impact on stress levels experienced by the sheep, which would be difficult to account for. For example, there will be an enhanced stress response to subsequent handling in mulesed sheep, additional stress due to more frequent handling and treatment in unmulesed sheep and a small proportion of the mulesed sheep that are struck.

Mulesing confers other advantages than just protection from breech strike, some of which impact on the stress to the sheep. These are reduced wool staining and dags (wool in the perianal region that is contaminated with faeces), reducing the need for dagging (removal of dags), dipping and crutching, easier shearing and an ability to time shearing to optimise wool quality rather than minimise the risk of flystrike, increased lamb growth, reduced mortality, reduced chemical usage and risk of residues in the wool and finally, reduced labour requirement for inspecting and treating sheep. Reduced need for tail docking, drenching and shearing can also be considered a result of mulesing, because these procedures are alternative methods of reducing the prevalence of the disease (Heath 1994).

The widespread adoption of the mulesing operation in the mid-to-late 20th Century, as a successful method of protecting against flystrike, meant that few other methods were researched, and the lack of research funding in the 1990s further delayed any search for viable alternatives. Since the Australian Wool Industry (AWI) representative body offered to phase out the mulesing operation from the end of 2010, there have been unconfirmed reports of successful development of a clip which can be applied to the wrinkles, causing them to fall off shortly after following skin necrosis (AWI, undated). Although application of rubber rings to the tail or testicles of sheep has been demonstrated to cause acute pain for at least several hours (Peers *et al* 2002) and probably several days (Thornton & Waterman-Pearson 2002), the clip is believed to produce less of a stress response than mulesing, as evidenced by physiological, growth rate and behavioural indicators (Hemsworth, personal communication 2008), perhaps because of reduced innervation and/or sensory receptors in the perianal skin compared with the tail or testicles.

Alternative methods of controlling flystrike

Shearing and crutching

Shearing permits the wool to dry more quickly, as it is short and more exposed to the drying elements of sun and wind. In Merino sheep, the fleece is thicker than other strains of sheep and takes longer to dry after the rain (Tellam & Bowles 1997). Shearing also improves the efficiency of insecticides, as they are more readily able to penetrate the wool and reach the skin (Tellam & Bowles 1997). Crutching additionally removes dags and urine-stained wool from the breech area, thereby decreasing its attractiveness to flies.

Early warning systems

“One of the principal weapons in flystrike management is anticipation — early warning of the activity of blowflies before sheep become at risk” (Heath 1994). However, effective anticipation requires use of new technologies for some producers — computer management, automated weather recording stations for example — as well as greater co-operation between neighbouring producers. Heath (1994) further believed that “the reasons for the continued losses are manifold, but the root of the problem lies in ignorance and lack of communication”. The time trends in blowfly numbers are consistent, showing a seasonal cycle with numbers increasing with temperature and time since the start of the grazing season in the United Kingdom, as well as a series of semi-discrete generation peaks over the grazing season (Cruickshank & Wall 2002). This suggests that early, intense farmer intervention is the best method to reduce *Lucilia* spp populations and flystrike. Later in the season, attempts to reduce strike by a reduction in the fly population are less likely to be effective. A model of *L. sericata* infestation of sheep in the United Kingdom has been developed by Wall *et al* (2000), which includes a blowfly lifecycle submodel to estimate the seasonal pattern of abundance and a sheep submodel with the following components: pasture worms, fleece and weather characteristics and sheep susceptibility. The model predicts the emergence of fly waves throughout the summer, with 3–4 generations in an average summer. In the early stages of summer, the strike rate is predicted to be limited by fly populations and in the later stages by sheep population.

Flystruck sheep display characteristic behaviours, in particular standing with their head lowered, twitching their tail and trying to bite the affected area (Anderson *et al* 1988). Many farmers are aware of these behaviours and regularly assess the prevalence of flystrike in their flocks. In the early 1980s, New Zealand farmers reported an increased prevalence and seasonal duration of flystrike, which was later shown to coincide approximately with the introduction of *L. cuprina* into that country (Heath & Bishop 2006). Routine and careful examination will reveal most cases but there may be 10–15% of cases that are difficult to detect. These provide the reservoir of infection for future infestations, since the major organism, *L. cuprina*, is an obligate parasite of live sheep, at least in the arid zones (Anderson *et al* 1988). It also has a high requirement for proteinaceous feed

for rapid population expansion, provided principally by sheep faeces (Wardhaugh *et al* 2008). Regular examination is required at all times of year since blowfly strikes are a year-round phenomenon, even during severe drought conditions (Anderson *et al* 1988; Heath 1994). The weather conditions required for the development of fleece-rot have been enunciated (Wardhaugh *et al* 2001). A sequence of wet days poses the greatest risk, compared with a number of discrete events. Belschner (1937a,b) observed that at least 100 mm of rain over 4–6 weeks is required, and Hayman (1953, 1955) found that if the rainfall is 100 mm or more in a month, including eight or more wet days, then the chance of fleece-rot is high (0.89).

As well as farmers being aware of the weather conditions likely to make sheep susceptible to flystrike, good husbandry, in particular the control of concurrent diseases that predispose to flystrike, such as the treatment of footrot, will play a major part in effective flystrike control.

Management to control diarrhoea

Diarrhoea is more prevalent in sheep grazing improved pastures and following rapid grass growth after rains. Short grazing of pastures by heavy stocking keeps grass in a vegetative state, with low fibre contents, which is then rapidly digested in the rumen, fostering an increased turnover through the gastrointestinal tract. Providing fibrous supplements can reduce dags and thereby the attractiveness of sheep to flies (Davidson *et al* 2006). Other predisposing factors for diarrhoea in sheep are helminth infestation, fungal endophytes, low moisture content in pasture grasses, rapid changes in diet (with insufficient time for the rumen microflora to adjust), and diseases of the gastrointestinal tract.

Sheep grazing policy is critical in controlling the formation of dags, which attract the flies (Waghorn *et al* 1999). They should be grazed on high ground and exposed to maximum wind flow at times when they are prone to flystrike (Heath 1994). Grazing pastures with condensed tannins, such as birdsfoot trefoil (*Lotus corniculatus*) or sulla (*Hedysarum coronarium*) also reduces dags, although the mechanism remains unclear because faecal moisture content is not affected. High condensed tannin contents in the pasture may reduce the risk of diarrhoea because of the binding of protein to reduce its digestion rate. The pastures with condensed tannins, which are often difficult to establish and maintain, can be integrated with other conventional pastures, whilst retaining the benefit to the sheep of reduced dags (Waghorn *et al* 1999; Leathwick & Heath 2001). Waghorn *et al* (1999) developed a method of determining the likelihood that faeces will stick to wool by dragging the wool across faecal samples, which demonstrated that pelleted faeces and firm stools do not adhere to wool, but loose faeces and diarrhoea do. The latter is most likely if the moisture content of the digesta is not reduced below 80% during its passage through the large intestine, having entered at about 90% moisture (Waghorn *et al* 1999). Grazing pastures after heavy rain is another risk factor, since digestion is impaired if the moisture content of ingested herbage is more than approximately 86% (Phillips *et al* 1991).

As well as nutritional management to control diarrhoea, control of gastrointestinal worms, for example by regular drenching, will help to reduce diarrhoea on the farm and thus susceptibility to flystrike (Rendell *et al* 2002).

Strategic application of insecticides

In the view of Heath (1994), “dipping is still the most cost-effective means of protecting sheep from flystrike”. Ectoparasiticides have been applied to domestic animals for thousands of years, even before the Christian era, but dipping and other procedures for soaking the sheep’s fleece require high standards of management (Heath 1994).

The principal insecticides used during the 1950s in Australia were dieldrin and aldrin. When dieldrin resistance became widespread in 1957/58, the organophosphate insecticide, diazonon started to be used. Diazonon resistance appeared in 1965/66 (Shanahan & Hart 1966), and the mulesing operation then became more regularly used (Eastoe 1966). Nevertheless, in 1972–4, 85% of properties in New South Wales were still using diazonon, with the remainder using diethyl fenthion, chlorfenvinphos or bromophos (Watts *et al* 1979). The Australian Pesticides and Veterinary Medicines Authority (APVMA) now propose to cancel the registration of diazonon, so that it will no longer be available for use in portable or fixed-plunge dipping, shower dipping and hand and auto-race jetting. This is because of concerns regarding the breakdown to more toxic substances, such as monotep and sulfotep, particularly when in an oil rather than water-based diluent, causing an elevation in red blood cell cholinesterase in humans (APVMA 2006). Resistance also occurs to diazinon and other organophosphorus insecticides in *L. cuprina* and *L. sericata* (Heath 1994). It is still available for use in Australia as a wound dressing or for treatment of individual sheep (APVMA 2006).

Alternative chemicals for blowfly control are cyromazine, dicyclanil, diflubenzuron, spinosad and triflumuron. A comparison of protection against resistant and non-resistant *L. cuprina* larvae in the laboratory, determined that the most effective organophosphate insecticide was chlorfenvinphos, providing 16–17 weeks protection, followed by propetamphos, dichlorofenthion and diazinon, which provided 15, 12 and 11 weeks protection, respectively, against the resistant strains (Wilson *et al* 1996). All provided approximately 20 weeks protection against the non-resistant strains. Under moderate risk, difluorobenzon protected for 110 days when used at 1,000 ppm and 170 days at 1,500 ppm (Hughes & Levot 1987). Under more severe fly pressure, 58 days protection (the same as diazinon) was provided by difluorobenzon at concentrations up to 2,500 ppm. *Bacillus thuringiensis*, the classical bacterial insecticide, has some isolates that are toxic to blowflies (Sandeman 1992), but it does not give as long a protection as standard insecticides. Its toxicity may be able to be introduced into common bacteria that inhabit the fleece of sheep, such as *Pseudomonas aeruginosa* (Heath 1994).

Most flies are homozygous to the genes conferring resistance to organophosphorus insecticides (Heath 1994). The best

strategy to preserve the effectiveness of insecticides is by allowing as effective a kill of the insects as possible. Ivermectin is only efficacious against *L. cuprina* for about two days, but slow release boluses could render this parasiticide capable of providing prolonged protection (Mahon *et al* 1993).

Genetic manipulation of sheep susceptibility to flystrike

There has been farmer selection against flystrike, because when an animal is struck twice or severely struck once it is usually culled (Heath 1994). This may be an indirect selection against scouring, which is often caused by nematode infection, in particular *Trichostrongylus* and *Ostertagia* spp (Heath 1994). However, there is little correlation between faecal worm egg counts (WEC) and diarrhoea, as measured by dag scores or faecal consistency scores (Karlsson *et al* 2004), making selection by WECs difficult. This is because certain sheep exhibit a hypersensitivity to ingested infective nematode larvae (Elkington & Mahoney 2007).

One of the main predisposing causes for flystrike is wetting of the breech wool with urine and, to a lesser extent, with diarrhoea (Watts *et al* 1979). Another risk factor is sufficiently moist conditions in the fleece to prevent desiccation of the eggs and larvae. Moist conditions associated with fleece rot during wet weather particularly predispose sheep to body strike. Sheep with folds of wool-covered skin in the breech area are susceptible to strike, even during relatively dry weather (Scobie *et al* 2005a,b). Such folds of skin were principally introduced into the Australian flock in the late 19th Century in the imported Vermont sheep (James 2006), but by the early 20th Century it was documented that sheep with wrinkled skin and dense wool were particularly susceptible to flystrike (James 2006). More recently, it has been demonstrated that sheep with wrinkles have reduced growth rates, low fecundity, slow shearing times and less valuable pelts, compared with sheep without wrinkles (Scobie *et al* 2005a,b). The breech conformation of the Vermont sheep has been described 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 regular manner” (Bell 1931, cited in James 2006).

As well as maintaining a moist environment suitable for larval growth, wrinkly sheep are also at increased risk of breech strike because the folds could become contaminated with urine. This, together with accumulation of yolk, sweat and skin detritus, leads to bacterial decomposition, producing an odour and inflamed, exudative skin, both of which are attractive to flies. Some sheep breeds, for example the Wiltshire Horn meat breed, have naturally bare breeches, but crossing Merinos with this breed reduces fleece weight and increases fibre diameter (Rathie *et al* 1994).

Other predisposing factors to flystrike in the Vermont sheep are a greater liability to cuts at shearing and crutching, greater liability to grass seed infestation and heavy wool yolk content (James 2006). Therefore, the objectives in breeding suitable sheep that are resistant to flystrike should

be to have few or no skin folds in the breech region, increased bare skin in the perineal region, a tail length that enables sheep to hold their wool out of the way when defaecating or urinating and short or no wool on the ventral surface, the sides, tip and base of the tail (wool is required on the dorsal surface for protection from the sun [James 2006]), and an enhanced immune response to larval infestation. An on-farm test of the reaction to an intradermal injection of larval extract has been developed and validated (see review by Tellam & Bowles 1997). Bimodal immune responses of different sire groups to an injection of *L. cuprina* larval extract suggests that selection for this trait could be beneficial (Hohenhaus *et al* 1995).

Tail length is very important in determining the risk of contamination with excreta, since tails that are too short prevent the sheep raising them during excretion, hence at least three vertebrae should be left when the tail is removed, so that the vulva and anus are adequately protected (Watts *et al* 1979; O'Halloran *et al* 1983). In addition, a tail that is too short cannot be twitched by the sheep to remove flies (James 2006). However, overlong tails create dags in some New Zealand meat breeds (eg the Perendale, but not the Coopworth [Scobie *et al* 1999]) and are easily soiled. The progenitor of the modern sheep, the Mouflon, is short tailed, but long tails were developed in British sheep breeds for the more extreme conditions in the cold mountainous regions. To this day, British sheep have their tails docked in lowland regions of Britain, but not in the hill areas. In Australia, tail docking is routinely administered (Ware *et al* 2000), but it is considered important in mulesed sheep to leave a 'V' of wool bearing skin extending one-third of the length of the tail to shade it from the sun, whilst exposing skin on the sides to prevent overhanging wool which is easily soiled (O'Halloran *et al* 1983). Research in both Britain and Australia has demonstrated that tail amputation reduces faecal soiling and hence reduces the risk of blowfly strike, by a factor of 3–6 (French *et al* 1994; Ware *et al* 2000, respectively). Failure to dock sheep's tails is likely to lead to more frequent crutching and/or jetting with parasiticide (Ware *et al* 2000).

Despite the clear correlation between wrinkly and woolly skin and susceptibility to breech strike, selection for plain breeches is believed to be unlikely, alone, to provide the level of protection comparable to mulesing (James 2006). So successful was the mulesing operation in controlling breech strike that 20th Century research concentrated on genetic selection for avoidance of body strike, ignoring breech strike which is actually more prevalent if no mulesing occurs (James 2006). In the absence of mulesing, it is likely that significant progress would have been made towards the production of sheep with greater resistance to breech strike. However, it has recently been determined that the genetic heritability of wrinkling is quite high (a mean of 0.34 from a review of 16 estimates [James 2006]), so good progress is possible. There has already been some selection against wrinkling characteristics in Australian sheep, partly because of its association with reduced fertility. Breech-bareness scoring systems have been developed and are reviewed by Scobie *et al* (2007). Estimates of the heritability of breech bareness in Merino sheep are high, at 0.46,

suggesting that the trait may be controlled by a major gene (Hebart *et al* 2006). Estimates of heritability in New Zealand crossbred sheep are also high (0.33 and 0.55) and correlate with scores of breech area soiling (Scobie *et al* 2007, 2008, respectively). Scobie *et al* (2007) identified an additional trait, length of bare skin under the tail, which had a heritability of 0.59 but did not correlate with the degree of soiling of the breech area. However, there is a slight but significant positive genetic correlation between breech bareness and fibre diameter, which could adversely affect wool quality for finewool producers, and a negative correlation with belly wool, suggesting that fleeces would require less skirt to be removed (Hebart *et al* 2006). Scobie *et al* (2002) has confirmed that in other breeds there is a lower incidence of strike in sheep with bare perineal skin. A joint project between the Commonwealth Scientific Industrial and Research Organisation (CSIRO) and the Department of Agriculture of Western Australia has determined that breech strike is more closely associated with wrinkles than bareness in finewool Merino sheep (CSIRO 2007). Other factors, such as fleece rot could be selected for, but the genetic heritability has not yet been ascertained. A scoring system for breech traits (including breech cover and wrinkle, dags and crutch cover, as well as some general traits of relevance, such as fleece rot), has recently been developed by the sheep industry representative bodies in Australia, incorporated into a wide range of sheep and wool scoring systems (AWI/MLA 2007). CSIRO (2007) recommend that these are better assessed in older animals, perhaps at hogget stage. At one experimental site, intense selection of sheep with few wrinkles and a large, bare breech area from nearby producers' flocks, and operating through both the dam and sire lines over three years, has reduced the rate of breech strike in unmulesed sheep to that of unselected mulesed sheep (Murray *et al* 2007). There is also considerable between-breed variation in the degree of wool cover over the breech area, being naturally low in the following meat breeds: Wiltshire Horns, Border Leicester, Polled Dorset, Texel and East Friesian breeds. Where there is a risk of diarrhoea, males will be more susceptible to flystrike because the crutch wool boundary is closer to their anus than in females (Watts & Marchant 1977). Hence, ram lambs are more likely to accumulate dags than ewe lambs (Scobie *et al* 2008). The overall effect of gender is difficult to determine because of the greater risk of urine stain in the females (James 2006). Tail length is also strongly, genetically inherited and is believed to be a multigenic trait with some dominance of short over long tails (James 2006).

An enhanced immune response would be another possible method to reduce the pathogenicity of flystrike. However, this may be difficult to achieve by genetic manipulation because the protective response may be swamped by immunosuppressive antigens produced by rapidly growing larvae (Bowles *et al* 1996; Tellam & Bowles 1997). Sheep that are susceptible to breech strike are more likely to respond to larval presence with plasma leakage and, in particular, activated complement, and less likely to form a wheal over the damaged area (James 2006).

A delayed-type hypersensitivity, probably mediated by IgE, has been identified in some resistant sheep (Elkington &

Mahoney 2007). A flock selected for resistance to blowfly has developed increased inflammatory Type 1 immediate hypersensitivity response to excretory-secretory products of *L. cuprina* larvae, again mediated by IgE, as well as an increased complement C3 production (Elkington & Mahoney 2007). Larval responses include degradation of IgG at the wound site, a possible production of a cytokine-mimic to subvert a protective immune response, and possible down-regulation of host T-cell responses (Elkington & Mahoney 2007).

Fly control

Flytraps

Harvesting the flies provides a possible method of reducing the challenge to the sheep, but the traps have to be regularly attended. Offal is often used to attract the flies. An evaluation of flytraps in Southern Queensland between 1999 and 2001 reduced the incidence of flystrike by 38–55% (Ward & Farrell 2003). A field trial in England has demonstrated that traps reduced the incidence of blowfly strike caused by *L. sericata* by a factor of five (Broughan & Wall 2006). The mitochondrial genome of this blowfly has recently been published (Stevens *et al* 2008), which could eventually lead to improved control mechanisms through genetic modification. Trapping, therefore, has the potential to be a valuable and environmentally-acceptable fly control measure (Heath 1994), even though the main causative agent in Australia, *L. cuprina*, is much less represented in offal traps than other fly types.

Parasitoids

Parasitoid hymenoptera were released in New Zealand in the mid-20th Century but their prevalence 60 years later was only approximately 1% of blowfly larvae, mainly *Lucilia* spp, *Calliphora stygia* and *C. Hilli* (Bishop *et al* 1996). Under laboratory conditions, *L. cuprina* was successfully parasitised by the following wasp species: *Apahaerata aotea*, *A. manducator*, *Tachinaephagus zealandicus* and *Nasonia vitripennis*. It was not parasitised by *Phaenocarpa antipoda*, an endemic native wasp, about which there is little information. *A. aotea* and, to a lesser extent, *T. zealandicus* also utilise the dung-breeding dipteran, *H. varia*, which ensures that there is a refuge host in flystrike areas should there be a temporary absence of calliphorid larvae.

Vaccination

The development of vaccines against blowfly strike has been recently reviewed by Elkington and Mahoney (2007). An injection of *L. cuprina* larval extract results in increased antibody production to both this parasite and others (Hohenhaus *et al* 1995). Vaccination with larval antigens has achieved a 33% reduction in the incidence of strike and a 55% reduction in wound size (Bowles *et al* 1996). The mechanism is yet to be defined, but is likely to involve cellular responses, including T cells. An alternative approach uses hidden or concealed antigens, which are not seen by the larval immune response during the course of natural infection. The mechanism of larval growth inhibition relies on serum antibody, possibly through steric

hindrance, with anti-peritrophic membrane antibodies blocking the passage of nutrients and enzymes across the membrane. This method does not contain the size of the wound, instead it relies on the wound leaking serum to expose larvae to antibodies.

Topical applications to the breech area

Quarternary ammonium compound

This compound complexes with glucosamino-glycans under the skin and induces the formation of hard eschars, which slough off about four weeks later (Chapman *et al* 1994). It leaves an area similar in size to the bare area left by the mulesing operation. The compound is a skin irritant, but early responses are not as severe as those observed following mulesing (Chapman *et al* 1994). Consequently, sheep do not appear to develop an aversion to the operator since they do not link the treatment event with the pain, which takes three-to-four hours to develop. The behavioural response is less severe, with less hunched standing and more lying, but the physiological response is severe, comprising a major inflammatory response and severe pyrexia (Colditz *et al* 2009a). Application of a non-steroidal anti-inflammatory drug, carprofen, further reduces the behavioural response but does not mitigate the physiological response (Colditz *et al* 2009b).

Phenols and caustic potash

Phenols cause skin necrosis and stretching of bare areas (Morley & Johnstone 1983), and caustic potash (the Manchester technique) can achieve a similar result. Applying caustic potash to the breech area leaves a larger bare area than mulesing, but is likely to be equally or more painful (Morley 1949, cited in James 2006). However, both have tended to be discounted on the grounds that the chemical is highly toxic to humans (phenol) or overly time consuming to apply (phenol and caustic potash), compared with the mulesing operation.

Animal welfare implications

Flystrike is a seriously debilitating disease of sheep that has the potential to cause substantial stress to affected animals. The combination of susceptible sheep (after the importation of the Vermont Merino into Australia in the late 19th Century) and the arrival of the *L. cuprina* fly into Australia in the early 20th Century, have produced a high risk of flystrike for the national sheep flock. From the 1930s up until the present day, an increasing number of sheep farmers have been surgically removing skin from the hindquarters of their sheep — the mulesing operation — which results in a major reduction in the prevalence of the disease. The mulesing operation appears to have less impact on the stress levels to which the sheep are exposed than flystrike, but is conducted on the majority of Merino sheep in Australia, compared with the small proportion that suffer from flystrike. Since sheep farmers in Australia have agreed to terminate the procedure after 2010, they will be required to use alternative preventative methods, including genetic manipulation to reduce wool cover and skin wrinkles on the

breech, more frequent shearing, crutching and use of insecticide, early warning systems, flytraps and control of diarrhoea. Several new developments may improve farmers' ability to control flystrike, including vaccination, clips to remove breech wrinkles and topical application of skin tightening agents to the breech. These methods are less harmful than mulesing and provided they are effective, the welfare of the national sheep flock should be improved as a result of this change in strategy to contain the disease.

Acknowledgements

The author acknowledges support for this review from the organisation, People for the Ethical Treatment of Animals.

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