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Chemical Shearing in Sheep:

A Review with special reference to Cyclophosphamide as a defleecing agent

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Abstract Many chemicals have been tested in numerous studies since 1969 to establish the appropriate doses of compounds which can defleece sheep within a determined period of time, and which have no harmful side effects. Cyclophosphamide administered orally at the level of 30 mg/kg body weight is, at the present time, the most suitable drug. There are, however, some major problems which have yet to be solved, such as different responses of different locations on the body, the rate of wool regrowth before shedding, the need to protect the animals from environmental elements, and the difficulty of administering the drug to a large number of animals kept on range. It is concluded that the problems outweigh the advantages of chemical shearing at present.

1. Introduction

It has been known for a long time that as a side effect of drug treatment to arrest cancer, patients lose their hair temporarily. In 1969, while testing the effects of new chemicals, Homan *et al.* (1969) found that cyclophosphamide (CPA), when injected intravenously, induced wool loss in Suffolk sheep, and hair loss in Poodle dogs and Angora rabbits. These findings were confirmed the same year by Dolnick *et al.* (1969).

In recent years, the shortage and high cost of skilled shearers, combined with low wool prices, made the possibility of having sheep 'shear themselves' by using chemicals and unskilled labour an attractive one.

Although the idea of using chemicals for causing wool loss goes back to the mid-thirties, since 1969 a substantial number of research articles have been published on the subject of chemical shearing, or defleecing as it is commonly known. The purpose of this review article is to summarise the results obtained so far on this subject.

2. Chemicals Used for Defleecing

Panaretto *et al.* (1975) defined the ideal defleecing agent as "a compound with little or no general systematic toxicity that will remove wool in a predictably short period of time following dosing, and produce a minimal depression in subsequent wool growth".

Although CPA may not be the first chemical used intentionally for defleecing sheep, it has been by far the most popular, in view of its low toxicity, predictable performance and minimal side effects. Table 1 lists the major research with CPA chronologically according to the country where the work was carried out and general purpose of the study.

Many other chemicals were tested as defleecing agents, with various degrees of success. Mohn (1958), Ferguson *et al.* (1965), Chapman and Bassett (1970), Thwaites (1972) and Panaretto *et al.* (1975) tested the cortisone, cortisol, and cortisol synthetic analogues. Panaretto *et al.* (1975), Panaretto and Wallace (1978*a*, *b*, 1979) and Panaretto (1979) worked on dexamethasone and its derivatives. Panaretto and Wallace (1979) studied the effects of thiocyanate. Hughes (1959), Tunks *et al.* (1980), and Chapman and Rigby (1980) used N-[5-4(aminophenoxy) pentyl]-phthalimide, and the results of using this drug were summarised by Rigby *et al.* (1980). The use of mimosine and its derivatives as defleecing agents was reported by Reis and his colleagues (Reis, 1975, 1978; Reis and Tunks, 1978; Reis *et al.* 1975, 1978).

Most of these defleecing agents have proven to be unsatisfactory, because of their high toxicity or ineffectiveness. The present review deals mainly, and in some detail, with CPA as a defleecing agent; occasional mention of other agents is made. For more details on the other defleecing agents, the reader is referred to the review of Reis and Panaretto (1979).

3. Mode of Administration

The path by which the compounds enter the body may influence greatly their effects. Defleecing agents can be administered either subcutaneously, intravenously or orally. Oral and intramuscular routes are the most practical when handling a large number of animals.

In the early work of Homan *et al.* (1969) and Dolnick *et al.* (1969), wool loss was induced by injecting the defleecing agent (CPA) intravenously. In most of the work which followed, however, the drug was administered orally. Lindahl *et al.* (1970), Inskeep *et al.* (1971), Dolnick *et al.* (1970*a, b*) used a stomach tube, whereas Hohenboken (1972) and Tunks *et al.* (1980) used tablets in gelatine capsules to administer the drug. Reynolds *et al.* (1976) and Bogdanov and Kusnedelcheva (1977) used an aqueous solution, while Zelenskiĭ *et al.* (1973) simply mixed the drug in the feed. Panaretto *et al.* (1975) administered the drug opticortinol by injecting a suspension intraperitoneally.

Reis and Chapman (1974) showed that in sheep injected intravenously, or given CPA orally, defleecing took 2–3 and 2 weeks for the two methods respectively. Dolnick *et al.* (1969) and Zieger *et al.* (1972) also used these two methods of CPA administration with no apparent difference in results. Bogdanov and Kusnedelcheva (1977) showed that group treatment with CPA in the food was not as successful as individual treatment, the success rate with the latter being 100%. Reis (1978) reported that abomasal infusions of mimosine at a rate of 80 mg/kg body weight daily were equivalent to intravenous infusions. However, according to Schlink and MacFarlane (1978), oral administration inhibits rumen organisms for four days.

Hegarty *et al.* (1964) and Reis (1978) indicated that abomasal and intravenous infusions of mimosine are about equally effective for inducing cessation of fibre growth. The effectiveness of the different modes of administration rests on the speed of absorption and excretion by the body.

4. Doses

The daily recommended dose of CPA has been established as 30 mg/kg body weight, and that of mimosine as 40 mg/kg.

To establish the optimum dose of CPA which causes wool loosening from the body in a relatively short period of time, doses ranging from 5 mg/kg (Dolnick *et al.* 1979) to 150 mg/kg body weight (Zelenskiĭ *et al.* 1979) were investigated (Table 1). It has been widely found that doses below 20 mg/kg body weight were insufficient to cause wool loosening (Dolnick *et al.* 1969; Zieger *et al.* 1972; Hohenboken, 1972; Reynolds *et al.* 1972*a,b* and Jones-Davies *et al.* 1973). On the other hand, doses in excess of 60 mg/kg body weight were found to be harmful, and those in excess of 90 mg/kg to be lethal (Dolnick *et al.* 1969, 1970*b* and Zelenskiĭ *et al.* 1979). Brinsfield *et al.* (1972), however, observed no signs of gross toxicity at the 75 mg/kg level. Usually, a single dose of the recommended level has been found sufficient. Borrell *et al.* (1971) showed that while one injection of 20 mg/kg was ineffective, two doses of 20 mg/kg 2 days apart, three doses of 20 mg/kg at 2-day intervals, or 40 mg/kg were effective in loosening the fleece. Many studies demonstrated that the rate of wool loosening and regrowth is dose dependent (Reynolds *et al.* 1972*a,b*, Table 2). Higher doses would increase the rate of wool loosening, but decrease the rate of wool regrowth.

Reis (1978) reported no adverse effects following intravenous infusions for 2 days of amounts of mimosine ranging from 40 to 80 mg/kg daily, apart from feed refusal by one sheep for a period of 5 days (given the 80 mg level). He encountered some toxic effects at twice the minimal effective dose (160 mg). Infusions at 240 or 320 mg/kg daily for 2 days caused death in all the sheep treated.

5. Defleecing Time

Defleecing usually occurs when the constriction in the wool fibre, caused by the defleecing agent, reaches the skin surface. Defleecing time was found to vary according to the defleecing *agent, to be dose dependent, and to differ among locations on the body. The optimum dose causes wool loosening, and makes defleecing possible within 2 weeks after the treatment.*

Homan *et al.* (1969) reported that 6 days after the administration of 30 mg CPA/kg body weight, the wool on the back and flanks began to loosen (Table 1). Wool loss progressed for 3 weeks, and involved most parts of the body except the face, ears and limbs. Dolnick *et al.* (1969) showed that doses in the range 10–30 mg CPA/kg body weight made it possible to defleece the sheep easily by hand about 7 days after treatment. Hourihan *et al.* (1970, 1972) were able to defleece the sheep 7 days after administering 24 mg CPA/kg body weight orally. Lindahl *et al.* (1970) reported that on the 8th day after treatment with 24 mg CPA/kg body weight, 3 sheep were defleeced very easily, 14 easily, and 3 with some difficulty. Reynolds *et al.* (1972*a*) showed that dependence of wool loosening on dosage occurred up to 30 mg CPA/kg body weight. Doses over that level had a similar effect. Hohenboken (1972) showed that of 25 sheep receiving 20 mg CPA, 6 showed no sign of loosening of the fleece 4–5 weeks after treatment, compared with 1 out of 17 ewes treated with 25 mg/kg body weight. The average time from dosing to defleecing for the two treatments was 25.4 and 14.8 days respectively.

In two trials, Hudson *et al.* (1974) reported a significant difference in number of days elapsing between dosing and defleecing between 15 mg CPA/kg on the one hand and 20 or 25 mg/kg body weight on the other.

Reynolds *et al.* (1976) reported that the wool on sheep treated with 20 mg CPA/kg body weight was retained more tightly on day 6 after treatment than on sheep treated with 27 mg/kg. By day 8, however, the dosage effect had narrowed appreciably, and was nonsignificant. Roberts and McMahon (1972) showed that delay in manually defleecing the sheep can result in excessive loss through premature shedding of wool before it can be harvested.

6. Metabolism of the Drugs

The duration of the action of chemical agents depends on the time they remain in the body. Some are rapidly metabolised and excreted by the organism.

Bakke *et al.* (1972) showed that the major route of excretion of CPA was the urine (70–90% of the dose), and the mechanism of metabolism was oxidation of the CPA ring followed by hydrolysis. They could identify 8 urinary metabolites from a single oral dose of CPA. Schlink and MacFarlane (1978) reported that the metabolites formed by CPA disappeared from the urine within two weeks. Rougeot and Thébault (1975*b*) found no residue of CPA in the meat; they attributed this result to rapid degradation of the agent by the body.

Hegarty *et al.* (1964) and Reis (1978) showed that continuous abomasal infusion via a cannula and intravenous injection of mimosine are about equally effective for inducing cessation of fibre growth. Mimosine administered orally is degraded by the microflora of the rumen, and the amount reaching the abomasum is thus greatly reduced. The technique of utilising reticular groove closure to administer mimosine directly into the abomasum was not effective, because of the rapid absorption and excretion of the drug. Reis (1978) showed that mimosine is rapidly absorbed and equally rapidly removed from the body. Accordingly, no harmful metabolites are formed (Reis and Panaretto, 1979).

7. Mechanism of fibre removal

All defleecing agents weaken the wool fibres to loosen the wool, and eventually the fleece is shed.

Brinsfield *et al.* (1972) defined the action of CPA to be "the temporary alteration of cell function and cytoplasmic degeneration in some of the germinative cells". Large numbers of cytoplasmic inclusions containing acid phosphatase, indicative of cell degeneration, were observed. Consequently, normal wool growth was altered. Reis and Chapman (1974) showed that these degenerative changes occur one hour after dosing. At one day, the proliferation of the fibre cells and inner root sheath ceases. Fibre growth is completely inhibited before the fourth day. Regeneration of follicles starts before the 14th day, and at the 21st day regrowth is apparent above the skin. Sebaceous glands are still enlarged 36 days after the treatment. An infiltration of the dermis by lymphocytes, possibly leading to leucopaenia, was reported.

Mimosine arrests cell division in the follicle (Hegarty *et al.* 1964) by inhibiting DNA synthesis (Ward and Harris, 1976). Isomimosine seems to have the same effect as mimosine (Reis *et al.* 1978). Brinsfield *et al.* (1972) reported that, with the cytoplasmic degeneration, fibre cells are altered, therefore fewer cells form the wool fibre, thus causing focal constriction.

Reynolds *et al.* (1972*a*) determined that CPA constricted each individual wool fibre. The fibre was then weakened at the point of constriction, so that it broke when the growth of the fibre carried the constriction to the surface of the skin. Methionine, administered by abomasal infusion, caused a partial degradation of fibres before emergence from the skin (Chapman and Reis, 1978).

Reynolds *et al.* (1972*b*) reported that dosage accounted for the difference in the nature of the constriction influencing wool retention. Panaretto *et al.* (1975) estimated that wool growth had to be reduced below 20% of its pretreatment value to obtain shedding of the fleece 15–20 days after treatment.

8. Effect of Animal Condition Prior to Treatment

The optimum dose necessary for defleecing sheep depends on body weight. The condition of sheep and the management under which they are raised also have an influence on the amount of chemical needed for defleecing.

The effect of CPA does not seem to be influenced by deprivation of feed or water prior to treatment (Schlink and MacFarlane, 1978; Dolnick *et al.* 1972). However, according to Hudson *et al.* (1974), CPA should not be used on sheep prestressed nutritionally because of the higher mortality observed. The results (Table 3) showed that ewes fed above maintenance level took less time to defleecing than ewes fed only maintenance level.

Reis and Tunks (1978) showed that an intravenous infusion of mimosine at the rate of 80 mg/kg daily for 2 days in sheep on a 600 g roughage-based diet resulted in consistent defleecing. When the daily ration was lowered to 300 g, the same amount of mimosine was required for defleecing; however, when a 4-day fast was imposed 3 days before the infusion, only half the amount of mimosine was required for defleecing the sheep. The authors concluded that fasting or low dietary intake had resulted in an increase in the concentration of mimosine in the plasma. The same observation was made by Reis *et al.* (1978) when the mimosine was administered orally. They reported that a single oral dose of 400 mg/kg body weight was needed for defleecing when the daily ration was 600 g of a mixture of chopped lucerne hay and oat grain. When the daily ration was doubled to 1200 g, the dose had to be increased to 600 mg/kg body weight.

Reis and Tunks (1978) stated that a high intake of energy coupled with large amounts of amino acids available for absorption from the small intestine (generally supplied by casein), one week before the infusion of mimosine, prevented any loss of wool. Reis (1969) suggested that casein supplementation increased wool growth, and reduced susceptibility of the follicle bulb cells to the effects of mimosine. According to Schinckel (1962) and Short *et al.* (1965), these dietary conditions led to an increase in number and size of the follicle bulb cells which divided more rapidly, cancelling the effect of mimosine.

Gordon (1980) suggested that the plane of nutrition greatly influenced the success of wool harvesting. A 30% increase in the depilation force was noted when the food intake changed from 600 to 1200 g per day.

9. Effects on wool yield and characteristics

Yield from defleeced sheep is generally slightly higher than from shorn sheep, the difference being the amount of wool usually left on the sheep after shearing. The quality of wool, whether shorn or defleeced, is essentially the same, except for stable length, which is slightly longer in defleeced sheep.

Hourihan *et al.* (1970, 1972) divided 40 sheep into two groups. Twenty of the sheep were given an oral dose of 24 mg CPA/kg body weight in 1969. The other 20 sheep were used as controls. The treated sheep were defleeced seven days after treatment, and the controls were shorn two days later. The wool growth period was about 15 months for both groups. The results of the experiment showed that wool weights obtained at each processing were similar in the two groups (Table 4). In yield percentage, the differences between the two groups were significant. These differences were attributed to higher yields of top and lower yields of noil from the chemically defleeced wool. The difference in the ratio of tops to noils (7:1 in defleeced vs 6:1 in shorn sheep) may be attributed to the short fibres resulting from second cuts in the shorn group.

The biggest difference between the treated and control groups was in staple length. The treated group had fleeces 0.88 cm longer than the controls. This difference should be expected, however, since the treated sheep were defleeced completely to the skin, while some wool is usually left on sheep in conventional shearing. As for fibre diameter, the difference between the two groups was negligible.

To study the effect of chemical shearing on subsequent growth and wool characteristics, the animals used in the first year of the experiment were kept for another year. The treated animals gained 24.7 kg body weight during that year compared with 25.1 kg for the control group. Half the animals treated with CPA the previous year were again treated, and the other half were shorn. The same applied to the sheep shorn in the previous year. Wool production and characteristics in the four groups are presented in Table 4. The results show that there is an advantage in chemically shearing wool. This advantage extends to the following shearings. A study conducted in France showed that the fleece characters of the defleeced sheep were improved, particularly yield, which increased by 10% (Rougeot and Thébault 1975*b*).

After defleecing, the wool grew on a bare and dry skin with a well ordered structure, and consequently the fleece did not retain dust or other particles. Hohenboken (1972) found that there was a high frequency of black fibres in initial regrowth of Hampshire and Suffolk sheep following treatment with CPA.

Reis (1978) and Reis *et al.* (1976, 1978) reported that following the administration of CPA or mimosine, the growth rate in length and the diameter of the fibres increased. They showed that with the use of mimosine, the sulphur content of the wool increased, and the content of high-tyrosine proteins decreased. However, after 9–11 weeks, these changes returned to normal except for fibre diameter, which was found to increase by up to 1 μm. Reis *et al.* (1978) suggested that there may be compensatory growth of wool.

9.1 Wool regrowth

Wool regrowth is essential for the well-being of the defleeced sheep, since it protects them from adverse climatic conditions. High dosages of the defleecing agents retard regrowth.

Homan *et al* (1969) showed that wool regrowth was evident within 4 weeks of defleecing. Dolnick *et al.* (1969) reported that when the fleeces were removed 7 days after treatment, the skin was completely bare, no regrowth being observed at this time. Reynolds *et al.* (1972*b*) showed that the wool regrowth appears later with increasing doses of CPA. An effect of dose on wool regrowth was not observed by Hohenboken (1972). He mentioned that all ewes defleeced within 18 days of treatment, regardless of dose level, were essentially bare after defleecing. In two trials, Hudson *et al.* (1974) reported contrasting results on the effect of dose on the rate of wool regrowth at time of defleecing.

10. Effect of Defleecing on Reproductive Performance in the Ewe

The administration of the recommended doses of a defleecing agent at any stage of pregnancy seems to have no adverse effect on the survival of the embryos or on their future wool production.

Dolnick *et al.* (1970*a*) showed that there were no adverse effects on 4 pregnant ewes treated with a single dose of 25 mg CPA/kg body weight, 19, 27, 56 or 60 days before lambing. Skalka and Vrzgula (1978), working with 31 pregnant Merino ewes administered 30 mg CPA/kg body weight at 40–50, 90–100 or 120–130 days of pregnancy, confirmed the findings of Dolnick *et al.* (1970*a*), *viz* the absence of adverse effects on the ewes and their lambs. A study conducted over a 4-year period, in which pregnant ewes were administered 15, 20, 25 or 30 mg CPA/kg body weight, was reported by Schlink and MacFarlane (1978). The results showed that the treatment had no measurable long-term effects on the ewes, either on wool production or on the lambs they reared. A long-term study was also reported by Zelenskiĭ *et al.* (1979), in which it was found that 30 mg CPA/kg body weight had no adverse effect on general health or reproduction of ewes in the next 3 years.

Shelton (1972) studied the effect of CPA throughout the entire reproductive cycle. He reported no effect of the drug on length of the oestrous cycle when administered any time between days 0 and 14 of the cycle. He mentioned, however, that if administered on days 15, 16 or 17 of the cycle, the drug might have an inhibitory effect on ovulation, in a manner similar to that reported in the rat. Shelton (1972) also reported that CPA had no effect on embryo survival during the pre-implantation period, nor during gestation. He observed an adverse effect on the survival of twin lambs whose dams were treated with CPA during the last 10 days of pregnancy. Only 37.5% of these lambs survived. Also, of two sets of triplets born to treated ewes, none survived. Borrel *et al.* (1971) showed that treatment with CPA had no adverse effect on lambs suckling treated ewes. This was later confirmed by Hohenboken (1972). Rougeot and Thébault (1975b) showed that, over a period of 5 years, the average size of the litter and birth weight of the lambs from treated ewes was 1.10 lambs and 3.88 kg respectively compared with 1.11 lambs and 3.90 kg for the control eyes.

11. Effect of Defleecing on Ram Fertility

Because defleecing agents affect cells with great mitotic activity, it was thought that it may also affect sperm cells which fall into this category. The results obtained on the effects of defleecing agents on male fertility indicate that the doses usually needed for defleecing are safe for use in rams to be used for mating. However, it is not desirable to treat breeding rams within 7 weeks of initiation of the breeding season.

Inskeep *et al.* (1971) treated Hampshire rams with either 25 or 40 mg CPA/kg body weight, and compared their semen quality with that of untreated controls. No difference was found between the control rams and those treated with 25 mg/kg in concentration of spermatozoa, whereas those treated with 40 mg CPA/kg experienced a decrease in concentration of spermatozoa during the period from 42 to 53 days after treatment. Semen volume and percentage motility were lower and percentage of abnormal cells was higher in the group given the higher dose. In a second experiment, rams treated with 0, 30 or 40 mg CPA/kg body weight were placed with ewes whose oestrus was synchronized on the 45th day after treatment. The conception rate of the ewes mated to rams of the three groups was 76, 79 and 55% respectively. The reduced fertility was apparent only in some rams and only when accompanied by a reduction in sperm concentration of the semen. Shelton (1972) treated 5 rams with 39 mg CPA/kg, exposed them to a group of ewes for 10 days, and compared their mating ability with that of 5 untreated rams. He found that, except for one treated ram, the rams marked approximately the number of ewes to be expected from an exposure of 10 days (66.7% for controls, 56.7% for treated rams). However, fewer ewes conceived to matings with treated rams than with control rams (23.4 and 47.9% respectively), the difference being significant. Shelton (1972) explained the reduction in mating vigour and fertility by a transitory or temporary reduction in white cell count and some degree of anorexia.

Gabris *et al.* (1973) showed that 22 mg CPA/kg body weight had no adverse effect on Merino rams, apart from some signs of toxicity at the time of administration.

12. Factors Influencing the Success of Defleecing

12.1 Location of the wool on the body

Wool fibres are not homogeneous in length and fineness on the entire surface of the sheep. Those on the shoulder are the finest, and those on the belly and leg are the coarsest. It has been found that the loosening effect of defleecing agents is related to the physical characteristics of the wool fibres, hence wool from certain areas of the body can be defleeced sooner after treatment than that from other areas.

Lindahl *et al.* (1970), Reynolds *et al.* (1972*a,b*, 1976) and Hohenboken (1972) were consistent in finding that wool from the shoulder, side and back is the easiest to remove, whereas that on the head, belly, legs and britch is the most difficult. It has been suggested that chemical shearing could be used to separate the fine (more valuable) from the coarser (less valuable) wool. The problem, however, is that the animals have to be handled more than once. The different degree of wool loosening from the different regions of the body is a serious limitation of chemical defleecing, because some wool is lost from the first loosening areas before the whole animal can be defleeced easily.

12.2 Age

From the only experiment in which yearlings were compared with mature ewes, age seemed to have no effect on the number of days from dosage to defleecing, but had a highly significant effect on the number of days from dosing to 0.6 cm regrowth. The 6 days' difference in favour of the yearlings probably reflects more rapid wool growth for younger ewes. (Hohenboken, 1972).

12.3 Sex

The results from the literature are contradictory on the differences between the two sexes in their response to defleecing agents. It seems that the difference observed in some cases is due to other factors rather than to sex per se. *There is some indication that males are more sensitive than females to higher doses.*

Dolnick *et al.* (1970*b*), working on Rambouillets, studied the lethality and acute toxicity of CPA at 40, 60, 80 and 100 mg/kg live weight on rams and ewes. None of the rams (0 out of 6) survived the 80 and 100 mg doses, whereas they all survived the 40 and 60 mg levels. One ewe out of 3 died at each level of dosage.

Reynolds *et al.* (1972*a*) reported that the wool loosening score of rams was greater than that of ewes on days 6 and 8 after treatment, but less on days 10 and 12. The difference over the entire period was significant in favour of the females. The difference was probably due to the different loosening score of the head, since in the other regions of the body, the loosening rate was similar in the two sexes.

Reynolds *et al.* (1976) found that, although the loosening score of rams was slightly better than that of ewes at day 6 after treatment, by day 8 the difference had vanished, and both sexes showed a similar loosening score. On day 13, the rams had lost 45% of their wool, while the ewes had lost only 13%.

Reynolds *et al.* (1972*b*) showed that the rate of wool loss 16, 21 and 28 days after CAP treatment was markedly higher in rams than in ewes. The two sexes differed in their response to the doses applied, with the ewes responding most at the 30 mg level and the rams at the 20 mg level (Table 2). The authors attributed the greater loss in the rams to their greater activity and aggressiveness. The two sexes also differed in the rate of wool regrowth (Table 2).

12.4 Breed

The response to chemical defleecing agents may differ among breeds of different wool types, whereas within wool types, breeds respond to the chemical agents in a similar manner. From the *scarce evidence in the literature, it seems that breeds with long wool are the easiest and fastest to defleece, whereas fine- and short-wool breeds and those with an appreciable percentage of kemp fibres are the most difficult to defleece and the least responsive to the defleecing agents.*

Rougeot and Thébault (1975*a,b*) showed that the number of days from dosing to defleecing varied according to the wool type. Sheep of long-wool breeds, such as the Texel, were ready for defleecing 8 days after dosing (40 ml of liquid containing 60 g/litre CPA), while those of short-wool type, such as the Prélapes du Sud, were ready 18 days after treatment. Merino (fine-wool), Limousin (medium wool of average length with a low percentage of kemp fibres) and Manech sheep (long wool with long kemp fibres) were ready for defleecing about 11 days after dosing. On the other hand, Karakul sheep, whose wool contains many kemp fibres, needed between 15 and 31 days for the wool to become loose enough for defleecing.

Hohenboken (1972), working on Hampshire, Suffolk and Willamette (a cross between Cheviot, Dorset and Columbia) purebreds and their crosses, found a significant breed differences in number of days from dosing to 0.6 cm regrowth of wool. Hampshires, Suffolks, and Hampshire × Suffolk crossbred ewes were slowest (43, 38 and 42 days respectively) and Willamettes (33 days) were most rapid in regrowth. Hampshire and Suffolk × Willamette crossbreds were intermediate (35 and 36 days respectively). Hohenboken (1972) attributed the better performance of the Willamettes to the Columbia breed in the Willamette's ancestry.

Reynolds *et al.* (1976), working on Dorset, Hampshire, Suffolk and Targhee sheep dosed at 20 or 27 mg/kg body weight, reported that the average wool loosening score (a score ranging from 1 = wool tight to 6 = wool lost in the course of the sheep's activity) for the four breeds did not differ on days 6 and 8 after treatment. No breed differences were noticed in the percentage of the skin area from which wool had been lost on day 13 after treatment. There were, however, differences among breeds in the length of wool regrowth. These differences were found to be in the same order as staple length before treatment, which prompted the authors to suggest that the effect of breed on regrowth was merely reassertion of the effect of breed on staple length. This observation was also reported by Gordon and Donnelly (1979). Hudson *et al.* (1974) found no breed differences among Rambouillet, Hampshire or Columbia sheep in number of days from dosing to defleecing or attaining 0.6 cm regrowth. The breed × dose interaction was also non-significant.

Gordon and Donnelly (1979) dosed 5 sheep from each of the Dorset Horn, Border Leicester × Merino, Corriedale, Polwarth, South Australian strong-wool Merino, medium Peppin Merino and fine-wool Merino types with 15 mg CPA per kg body weight. They studied the force and energy required to break staples clipped from the back wool of the sheep. The wool regrowth after treatment was monitored by dye-banding. The Polwarths and Corriedales had the longest staples, and the fine-wool Merino the shortest. There were breed differences in response to CPA, the fine-wool Merino, Border Leicester × Merino and Dorset Horn showed the least response in terms of staple breaking force or depilation force, while the medium-wool Merino, Corriedale, Polwarth and strong-wool Merino showed progressively greater responses. Gordon and Donnelly (1979) considered these differences to be related to differences in body condition rather than to different sensitivity of the wool follicles to CPA.

13. Other effects of CPA

McIntosh *et al.* (1971) showed that using CPA for defleecing cured 77% of sheep affected with mycotic dermatitis. The use of CPA in combination with streptomycin and penicillin cured up to 93% of such cases.

14. Conclusions

After considering all the factors involved and the advantages and disadvantages of chemical shearing, the symposium on chemical shearing held in 1977 in Moscow (USSR, 1979) concluded that "of all defleecing agents investigated, cyclophosphane (CPA) at a dose of 30 mg/kg body weight was the best. It did not adversely affect wool quality or the health of the sheep".

Research on chemical shearing started when scientists considered that it would be economically profitable to eliminate the high cost of mechanical shearing. The main advantage has been the eventual use of unskilled labour for the shearing operation (Terrill, 1969; Terrill *et al.*, 1973). Also, reduced quality of the wool caused by second cuts and skin damage caused by mechanical shearers can be avoided (Roberts and McMahon, 1972). Dolnick *et al.* (1969) suggested that the wool fibre length would be more uniform.

However, the potential disadvantages must be considered. The costs of chemical shearing include those of the drug itself, labour that must handle the flock an additional time, and possibly premature loss of wool under normal grazing conditions (Terrill, 1969). The premature shedding of the fleece from sheep within 2–3 weeks of dosing before new fibres grow to provide protection from the environment, leaves the animals susceptible to climatic stress such as cold and sunburn

(Reis and Panaretto, 1979). To overcome this problem, the producer must keep the animal indoors to avoid wool loss prior to harvesting, and to protect the sheep from the elements until reasonable regrowth of wool takes place. During this time, labour must be used to feed the animals. The effectiveness of covers placed on the sheep at treatment, to retain the fleece until sufficient regrowth has occurred, was tested, but the method was found to be unsuccessful.

One of the major problems is to apply chemical shearing to large-scale operations, especially with sheep kept continuously on range. The problem of different degrees of wool loosening on different parts of the body still remains unsolved. The varying sensitivity of some drugs according to the feeding management is another constraint yet to be understood fully.

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Table 1 Major work using CPA as defleecing agent

Year	Country	Authors	Dose mg/kg	Method	Days to defleece	General fields of study reported
1969	USA	Homan *et al.*	30, 40	IV	6–21	body locations
	USA	Dolnick *et al.*	5 to 90	IV, 0	7	mechanism of defleecing
1970	USA	Dolnick *et al.*	25	0		female fertility
	USA	Dolnick *et al.*				wool characters, effect of sex
	USA	Hourihan *et al.*	24	0	8	wool characteristics, first defleecing
	USA	Lindahl *et al.*	24		8	body locations
1971	USA	Inskeep *et al.*	25, 30, 40	0		male fertility
	Australia	McIntosh *et al.*	25			effectiveness for treating dermatitis
	France	Borrel *et al.*	20, 40, 60			wool characteristics
1972	USA	Bakke *et al.*		0		mechanism of defleecing
	E. Germany	Zieger *et al.*	10–50	IV, 0	7–8	
	Australia	Roberts & McMahon	20, 25, 30	0		wool characteristics, loss
	USA	Reynolds *et al.* (*a*)	15, 20, 30	0	to 12	wool characteristics, location, sex effect
	USA	Reynolds *et al.* (*b*)	15, 20, 30	0		wool characteristics, location, sex effect
	USA	Hourihan *et al.*	22.7	0	7	wool characteristics, location, sex effect
	USA	Hohenboken *et al.*	15, 20, 25	0		wool characteristics, location, age, breed effects
	USA	Shelton	30			male and female fertility
	USA	Brinsfield *et al.*	25, 75	0		mechanism, effect on wool follicles
	Czecho-slovakia	Skalka *et al.*	20		8–21	health, condition, blood indices
1973	Czecho-slovakia	Gabris *et al.*	22		10	effect on rams
	Russia	Zelenskiĭ *et al.*	30		9–11	skin and wool characteristcs
	Rhodesia	Jones-Davis *et al.*	10–30		16–21	effect on pregnant ewes
1974	Russia	Zelenskiĭ & Saksanov	30			wool yield, characters, skin histology
	Australia	Reis & Chapman	30	IV, 0		wool growth, histology of skin
	USA	Hudson *et al.*	15, 20, 25	0	11–19	effect of nutrition and doses
	Russia	Nartova	30		10	CPA and other drugs
	Romania	Braileanu	20–30	IV, 0		effectiveness in relation to dose, age, etc.
1975	Romania	Braileanu	20–60			effect of dose, blood analyses
	France	Rougeot & Thébault *a*	30	0	11	repeated effect of CPA, bread, wool traits
	France	Rougeot & Thébault *b*	30			review of the method
	Australia	Reis *et al.*	30	IV, 0		wool regrowth measurements
1976	Russia	Nartova	30			suint content of the fleece
	USA	Reynolds *et al.*	20, 27	0		effects of sex, dose, location, breed
1977	Russia	Zelenskiĭ *et al.*	30			repeated treatment, breed, wool quality
	Bulgaria	Bogdanov & Kusnedelcheva	25	0	11	group treatment
	Bulgaria	Stoyanov & Nedelchev	30			skin histology before and after treatment
1978	Australia	Schlink & MacFarlane	15–30	0		repeated treatment, wool quality, regrowth
	Czecho-slovakia	Skalka & Vrzgula	30			effect on pregnancy
1979	Russia	Zelenskiĭ *et al.*	30 60–150	0 0	10–11	wool quality, carcass quality etc.
	Australia	Gordon & Donnelly	15	0		wool characteristics, body locations
1980	Australia	Gordon	12	0		wool loosening, other drugs, breeds

Table 2 Effect of CPA dosage on the rate of wool loss and regrowth.

Days after CPA treatment		Percentage of area with wool loss			Regrowth score[a]		
		15 mg/kg	20 mg/kg	30 mg/kg	15 mg/kg	20 mg/kg	30 mg/kg
Ewes	16	0	2	1	0.5	0.2	0.2
	21	1	24	52	2.9	1.5	0.0
	28	8	45	91	4.0	3.4	2.9
	36				7.8	5.1	4.3
Rams	16	4	28	35	0.2	0.4	0.0
	21	13	70	56	1.4	1.2	0.6
	28	33	98	69	3.4	4.0	3.0
	36				8.8	5.6	3.8

[a] 0 (no visible regrowth) to 11 (skin surface well covered, wool 3 to 5 mm in length)

Source: Reynolds (1972).

Table 3 Effect of dosage and level of feed on number of days to defleece in ewes.

	Ewes fed maintenance level		Ewes fed above maintenance level	
Dose mg/kg	No of ewes	Mean (day)	No of ewes	Mean (day)
15	16	18.7	10	18.6
20	17	15.8	13	11.6
25	14	14.3	13	10.5

Source: Hudson *et al.* (1974)

Table 4 Mean weights, yields and lengths from individual fleeces.

	First year 1969		Second year 1970				Averages	
	T[a]	C[b]	TT	TC	CT	CC	T	C
No. of sheep	20	20	10	10	10	10	20	20
Greasy weight (kg)	4.17	4.02	4.26	4.32	4.63	4.21	4.44	4.27
Scoured weight (kg)	2.40	2.32	2.47	2.42	2.75	2.29	2.61	2.35
Card sliver weight (kg)	2.22	2.12	2.31	2.22	2.55	2.08	2.43*	2.15
Top weight (kg)	1.89	1.76	2.11	2.00	2.34	1.81	2.22*	1.90
Noil weight (kg)	0.27	0.30	0.181	0.216	0.173	0.160	0.177	0.188
Yields in percentage:								
Clean scoured/grease	57.7	57.6	58.0	55.9	59.7	54.3	58.8*	55.1
Card sliver/clean scoured	92.5*	91.6	94.3	91.7	92.6	90.4	93.0*	91.0
Top/card sliver	84.8*	92.7	91.2	90.0	91.8	87.4	91.5*	88.7
Noils/top	14.7*	17.9	8.0	9.3	7.5	12.2	7.7*	10.7
Noils/top and noil	12.8*	15.0	7.2	8.6	6.9	10.7	7.0*	9.6
Top:noil ratio	6.99:1	5.66:1	13.5:1	11.6:1	13.8:1	8.7:1	13.6:1*	10.1:1
Length								
Staple length (cm)	9.76*	8.88	7.94	6.79	7.74	7.18	7.84*	6.98
Top length (cm)	6.22*	5.97	6.40	6.38	6.54	6.13	6.47	6.25
Percent under 5.08 cm	41.48*	44.56	36.82	33.40	36.07	38.12	36.44	35.75
Fibre diameter	26.95	26.54	29.67	29.44	28.41	27.97	29.04	28.71

* Differences are statistically significant.
T[a] treated in 1969 with CPA
C[b] control in 1969
TT treated in 1969 and 1970 with CPA
TC treated in 1969, not treated in 1970
CT not treated in 1969, treated in 1970
CC not treated in 1969 or 1970

Source: Hourihan *et al.* (1970 and 1972)

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