Review article

Progress in control of hydatidosis using vaccination—a review of formulation and delivery of the vaccine and recommendations for practical use in control programmes

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Abstract

A vaccine to protect sheep, goats, and bovines against hydatid disease caused by the cysts of *Echinococcus granulosus* is prepared as a recombinant fusion protein expressed in *Escherichia coli*. Solubilised inclusion bodies are injected, together with Quil A, subcutaneously on two occasions 1 month or more apart, and induce protection against infection which lasts for at least 12 months. A third injection given 6–12 months after the second injection induces a high and long-lasting protection against artificial or natural challenge infections. This review describes work carried out on the formulation, safety and efficacy of the vaccine under laboratory and field conditions, using artificial or natural challenges with *E. granulosus* eggs, followed by necropsy. Hydatid control programmes based on regular treatment of all dogs with the correct dose of a highly-efficient anthelmintic have sometimes not been successful in Continental environments. Access to dogs is difficult in summer because of the distances to summer pastures, and is often impossible in winter because of snow. A control program using strategic twice-yearly anthelmintic treatment of dogs is likely to be successful provided grazing animals are vaccinated as well. Vaccination as a control tool only requires the veterinarians to visit two times a year, and while the veterinarian is present, the dogs can be treated with anthelmintic for little additional cost. One visit should take place after the autumn kill of animals for winter consumption, and this is a good time to vaccinate animals born in the summer, and also all other animals while they are healthy and immunologically responsive. The other visit should take place in the spring, at which time animals born during winter can be vaccinated. Although a single immunization has been shown to induce a useful degree of protection, where possible it is best to give two initial injections, 1 month apart. If it is possible for veterinarians to stay in the field for 2 months in November/ December and March/April, in order to give the two injections, a more rapid onset of full protective immunity will initially be achieved than if the injections are given 6 months apart. A large-scale safety and efficacy trial involving 50,000 and 100,000 lambs in Qinghai and Xinjiang Provinces of China has taken place. Results have confirmed safety and efficacy. In most countries, prevalence of infection increases with age. The vaccine has no effect on established cysts, and therefore, in order to prevent the biomass of *Echinococcus* spp. from increasing, it might be an effective strategy to begin a control programme by vaccinating all animals. Because many of the older stock will already be

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infected, they will remain a source of infection for dogs for the average lifetime of the stock. Dogs will still be able to be infected from the older stock, and will continue to infect humans. We advocate that a vaccination programme be accompanied by education about hydatid disease, and anthelmintic treatment of dogs in late autumn and early spring. © 2002 Published by Elsevier Science B.V.

1. The Vaccine

Hydatid disease is the common terminology for cysts of the dog tapeworm parasite, *Echinococcus granulosus*. Cysts slowly grow in grazing animals that have eaten eggs of the tapeworm, and become infective to dogs after 2–5 years. The life-cycle is completed when dogs eat infective cysts. Humans become accidentally infected with the tapeworm eggs, and suffer hydatid disease because after 5–10 years the growing cysts often interfere with normal functioning of the liver or lung, or other organs where the parasite has lodged. Hydatid disease is common throughout the world where pastoralism is practised, and is particularly common in populations where education and hygiene are limited. The control procedures used to eliminate Echinococcosis from Iceland, the Falkland Islands, Tasmania and New Zealand are not sufficiently effective in continental environments. A vaccine to protect grazing animals against infection is an additional control method that focuses on grazing animals instead of the dog. Most grazing animals are already vaccinated against viral or bacterial diseases, and so a vaccine against a parasitic disease can fit into normal farm practice.

A cDNA library was created from *E. granulosus* oncosphere mRNA, and screened with antibody affinity-purified from a protein molecule which on SDS–PAGE existed as a doublet at 23 and 25 kDa (Heath and Lawrence, 1996). A number of clones were selected, expressed in the pGEX system (Smith and Johnson, 1988) and tested in New Zealand.

One clone, Eg95, was the most effective (Light-owlers et al., 1996) and all our work subsequently has used this clone.

This paper describes laboratory and field testing of the vaccine produced in bulk in *Escherichia coli*. Sheep and goats in Xinjiang Uygur Autonomous Province of China and in Chubut Province of Argentina where hydatid disease is endemic, were either given *E. granulosus* eggs orally, or were naturally challenged by grazing naturally-infected environments. Sheep and cattle in New Zealand were maintained in a quarantine environment and were given *E. granulosus* eggs orally.

2. The correct amount of vaccine protein and adjuvant

The correct amount of the antigen to make a suitable vaccine needs to be determined. It is necessary to carry out dose–response trials on the amount of antigen and also on the amount of adjuvant, once a decision has been made on the adjuvant of choice. There are a large number of adjuvants available, many of which are registered for veterinary use. A test of a number of adjuvants showed that Quil A (Brentag Nordic) was superior in its ability to promote the highest level and longest persistence of protection against a challenge infection with eggs of *E. granulosus*, while causing minimum host reaction at the injection site. The amount of antigen and amount of adjuvant produce additive effects up to a certain safety margin. We have found that the most effective amount of antigen is in the region of 50 μg of active molecule and best responses are obtained with 1 mg of Quil A for sheep and goats. The dose–rate for mature bovines is five times that recommended for sheep.

3. Formulation of the vaccine

Because Quil A is hydrolysed in alkaline conditions the vaccine has to be formulated in a slightly acid environment. The vaccine must withstand

freeze-drying and reconstituting so that the product will have a good shelf-life and can be distributed to the field in a form which will maintain activity under sometimes less-than-perfect conditions. The formulated vaccine is sterile-filtered into sterile vials, and freeze-dried. Quality Control and sterility testing is carried out on the freeze-dried product, using bacteriological and biochemical tests and immunization of sheep. It is important that the vaccine has at least a 12-month shelf-life at 4 °C. All production batches should be individually tested for potency in target animal trials. Potency is proven by monitoring the serological response of sheep in comparison with serum from immunized and protected sheep. The serological responses of a new batch of vaccine are normally tested in ten vaccinated animals. The vaccine passes the test if eight of the vaccinated animals show a serological response which is equal to or exceeds the serological response of fully protected vaccinated animals. The recommended storage temperature is 4 °C but the vaccine will retain better activity if stored at −20 °C, and has an indefinite shelf-life when stored at −80 °C. The sterile diluent (buffered saline at pH 6.8) which is used for diluting the freeze-dried vaccine should be sent with the vaccine. Any unused reconstituted vaccine should be stored at −20 °C for no longer than 1 month.

4. Delivery of the vaccine

It would be an advantage if the vaccine was able to be mixed with other vaccines. Preliminary work indicates that the vaccine will work effectively in the presence of an aluminium hydroxide-adjuvanted clostridial vaccine of five strains in one. The aluminium hydroxide actually enhances the effect of the Quil A on both the clostridial and the hydatid vaccine, despite aluminium hydroxide not being a useful primary adjuvant for the hydatid vaccine. The disadvantage of this combination is that the aluminium hydroxide vaccine cannot be freeze-dried. The shelf-life of a liquid hydatid vaccine which incorporates a clostridial vaccine needs to be determined. The hydatid vaccine can also be incorporated with other injections, includ-
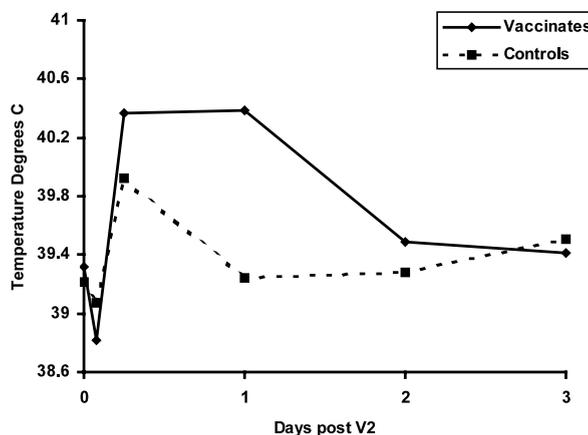

Fig. 1. A typical safety test of the Eg95/Quil A vaccine. Sheep are given double the recommended dose of vaccine on two occasions, one month apart. Rectal temperatures are measured at the times shown. Sheep are observed at each temperature measurement for signs of distress. Injection sites are measured weekly for 4 weeks after each injection and palpated to determine whether the lesions are painful.

ing injectable anthelmintics. The formulation that a particular country wishes to use will require the appropriate testing and registration in that country.

5. Safety tests—systemic and local reactions

Two injections of vaccine are initially given, 1 month or more apart, subcutaneously in the neck region. The site of the injection is monitored for at least a month after injection, recording the size of the lump if it develops, how long it takes to disappear and whether it causing pain or there is pain on palpation. At the same time any systemic reactions such as animals showing lethargy are monitored. To record pyrexia, regular temperature measurements are taken for the first 3 of days, or until temperatures return to the same as control animals. Limits are set on all safety factors, and if any are exceeded then the vaccine is not passed (Fig. 1).

Table 1
Necropsy results from an efficacy and longevity of immunity trial in Chubut, Argentina

Treatment	No. of lambs infected	Time from vaccination to challenge infection (months)	Numbers of cysts found at necropsy	Percentage protection
Controls	5	5	27, 211, 304, 474, 674	–
One vaccination	3	5	0, 57, 76	85
Two vaccinations	3	4	1, 3, 6	99
Controls	10	12	1, 45, 53, 87, 149, 157, 175, 182, 362, 735	–
One vaccination	10	12	3, 5, 6, 12, 20, 32, 32, 41, 74, 110	82
Two vaccinations	10 (2 died during the year)	11	0, 0, 0, 0, 0, 5, 10, 14	98

In April 1997, Merino lambs were 6 months old. They were raised and maintained throughout the trial on a farm of 10,000 ha shown to be free of *E. granulosus* infection in both sheep and dogs. Lambs were allocated to three groups: controls receiving no vaccination; a group receiving one vaccination; a group receiving two vaccinations given 1 month apart. Some lambs from each group were given *E. granulosus* eggs orally in September 1997, (5 months after V1, or 4 months after V2), and were necropsied 12 months later. Other sheep were orally infected in April 1998 (12 months after V1 or 11 months after V2) and were necropsied 8 months later.

5.1. Safety in pregnant animals

Often pregnant animals are vaccinated, so it is important to show that there is no increase in abortions, still-births or teratogenic effects. Sheep and cattle have been tested in their last third of pregnancy, and no problems have been seen. Results from a trial to vaccinate ewes immediately after mating, when the developing foetus is most sensitive, have also been good. Two hundred ewes were vaccinated and compared with 200 unvaccinated ewes. A proposed vaccination regime where all adult animals are given their first vaccination in the late autumn (see Section 10) will mean that most will be in the early stages of pregnancy when vaccinated.

5.2. Safety and Efficacy in young animals

Lambs and kids were vaccinated at 4 weeks of age (V1) and at 8 weeks of age (V2), and in another trial double doses of vaccine were tested in lambs at 4 and 8 weeks. There were no unwanted reactions, and no problems with the health of the animals have been observed. There was a good antibody response to the vaccine.

Some lambs received a third injection 6 or 12 months after the second. Safety and efficacy were tested initially, with challenge infection of *E.*
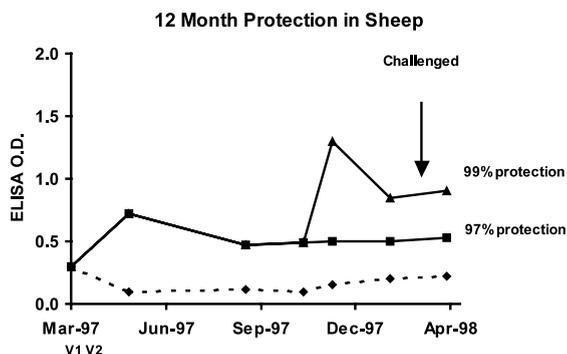

Fig. 2. Serological absorbances of vaccinated or control sheep from Xinjiang Province of China. Lambs were vaccinated against *E. granulosus* using the Eg95 recombinant vaccine. The aim of the trial was to determine the degree of immunity to an artificial infection with *E. granulosus* eggs 12 months after the lambs had been vaccinated. A group of sheep received a third vaccination 3 months before the egg infection. A high degree of protection was apparent 12 months after vaccination, marginally enhanced by a third vaccination. There was only one case of natural infection in this trial (one control sheep with one large cyst indicative of an infection 6 months before the challenge infection). The trial was conducted in Wensu County of Aksu Prefecture, Province of Xinjiang. A hydatid control programme had been in place in Wensu County for a number of years (Chi et al., 1994).

granulosus eggs being given either 1, 6 or 12 months after the second immunisation. The vaccine proved to be safe and well tolerated, and after 2 injections protected kids against an artificial
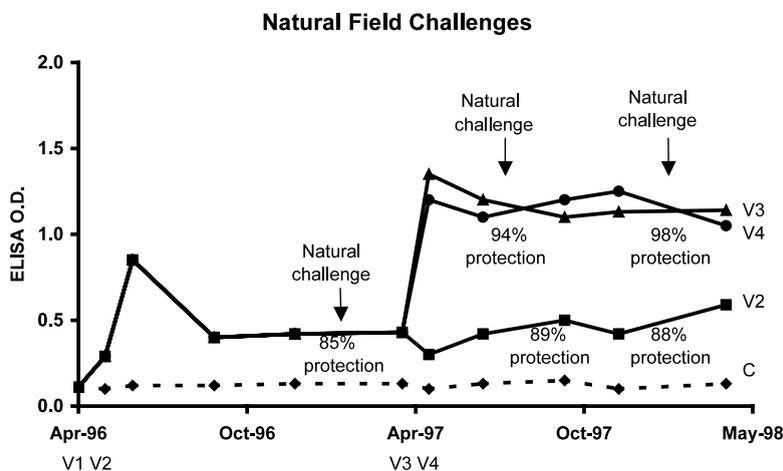
Fig. 3. Serological absorbances of vaccinated or control sheep from Xinjiang Province of China. Lambs were vaccinated against *E. granulosus* using the Eg95 recombinant vaccine. One group (V2) received two vaccinations only, at the beginning of the trial. Another group also received a third vaccination (V3) after 12 months and another group received two further vaccinations (V3 and V4) at 12 and 13 months. Necropsies carried out at the end of the trial revealed that two natural infections with *E. granulosus* eggs had occurred in the winter of 1966 and autumn of 1967. An artificial infection of half the sheep coincided with a further natural infection in the winter of 1998. Each infectious period could be clearly discerned by the respective size of the cysts. The vaccine induced good protection to natural infection after two vaccinations and a high and possibly long-lasting protection after a third vaccination.

challenge infection by 100% at 1 month and 83% at 6 months. Lambs were protected by 91% at 1 month, 84% at 6 months and 97% at 12 months.

6. Longevity of immunity

We have determined the longevity of immunity from two injections and then from three injections and then from multiple injections (annual booster). In Argentina it has been shown that a single injection will give significant immunity to natural challenge with *E. granulosus* eggs (Table 1). In China, two injections can induce about 85% protection against infection for 12 months in sheep (Fig. 2) and in the presence of field challenge this sort of protection level is maintained for at least another year (Fig. 3). If a 3rd injection is given 6–12 months after the 2nd then there is an anamnestic response, (much higher level of antibody generated and much higher level of protection-up to 100% protection) and this immunity can last up to 3 or 4 years (Fig. 4). In cattle, immunity after two injections is effective 12 months later, and is boosted to very high levels by a third injection (Fig. 5). To maintain the highest level of protec-

tion for the life of the animal the most effective regime is annual boosting of the immunity level in those animals which have received the three injection prime-boost and boost regime. However, sheep and cattle seem to react to the three injections of recombinant molecules with Quil A in very much the same way as humans react to diphtheria vaccine or hepatitis B. Two injections are needed at least 1 month apart to prime and boost the person, followed by a further injection 6–12 months later, which then gives a prolonged period of resistance. For protection against hydatid disease, a high level of antibody needs to be maintained, so as to kill any new invading oncospheres. This high level of antibody is important, because by the time memory cells are stimulated to make antibody after an oncosphere invades the body, the oncosphere has changed to an hydatid cyst and cannot be affected by the newly-stimulated antibody.

A 12-month protection trial was carried out where sheep were given two vaccinations and then challenged only once 12 months later. They were kept in a clean environment during that time, which was Wensu County of the Aksu Prefecture, Xinjiang Uygur Autonomous Province of China.
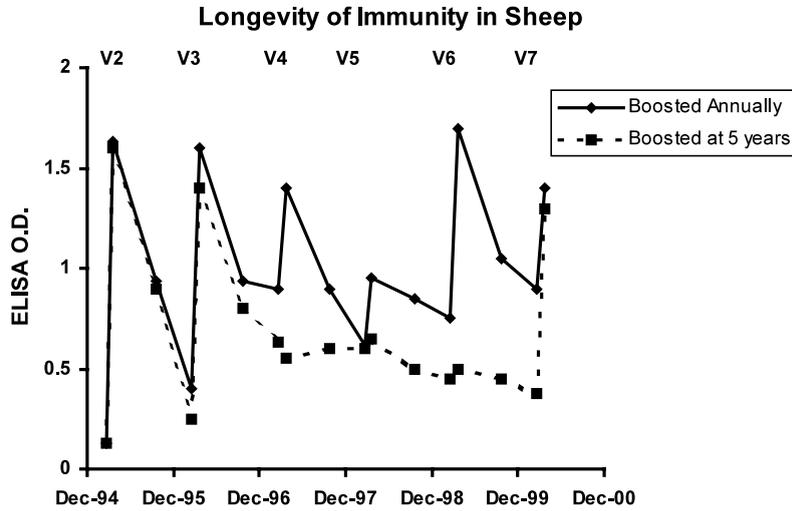
Longevity of Immunity in Sheep

Fig. 4. Serological profiles of groups of five sheep immunized at the beginning of 1995 with two injections of Eg95, given 1 month apart. Thirteen months after V2, both groups received V3. Thereafter, the boosted group received annual boosts, whereas the 'not boosted' group did not receive a further boost until 4 years after V3. An in vitro assay has been carried out on all sera collected during the 5 years. The oncosphere-killing ability of sera, which is highly correlated with antibody response to the Eg95 vaccine and to protection against infection with *E. granulosus* eggs, was effective in both groups except for some, but not all, of the serums collected at V3, and at V4 for the non-boosted group. (Those animals with ELISA OD below 0.4.)

Some of the animals were given a V3 boost just prior to challenge and were slightly more protected than those which had not only received V1 and V2. It was interesting that these animals, that had only received V1 and V2 some 12 months previously, were still 97% protected after 12 months (Fig. 2).

The duration of immunity can influence the various choices that can be made in a control
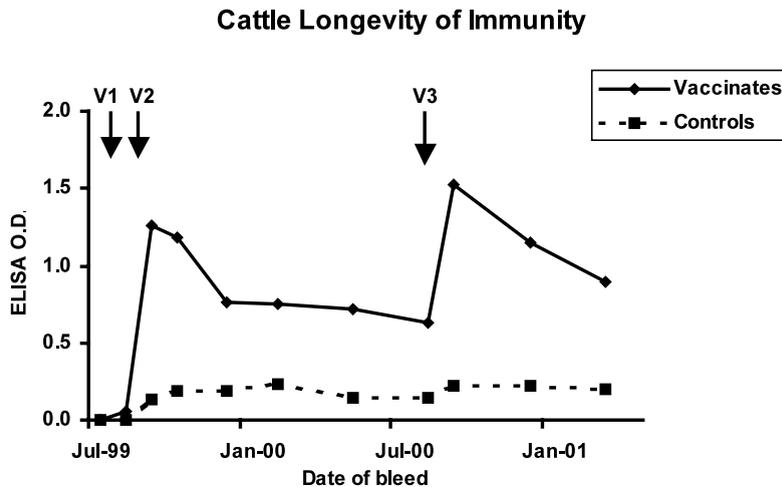
Cattle Longevity of Immunity

Fig. 5. ELISA absorbances of sera from cattle immunized by two injections of Eg95/Quil A given 1 month apart, and a third injection given 12 months after V2. Cattle received five times the sheep dose of vaccine. At 1, 6, 12 and 13 months after V2, groups of immunized and control not immunized cattle, were given 10,000 freshly-collected *E. granulosus* eggs intrarumenally. Protection was 89% at 1 month, 91% at 6 months, 93% at 12 months and 99% at 13 months.

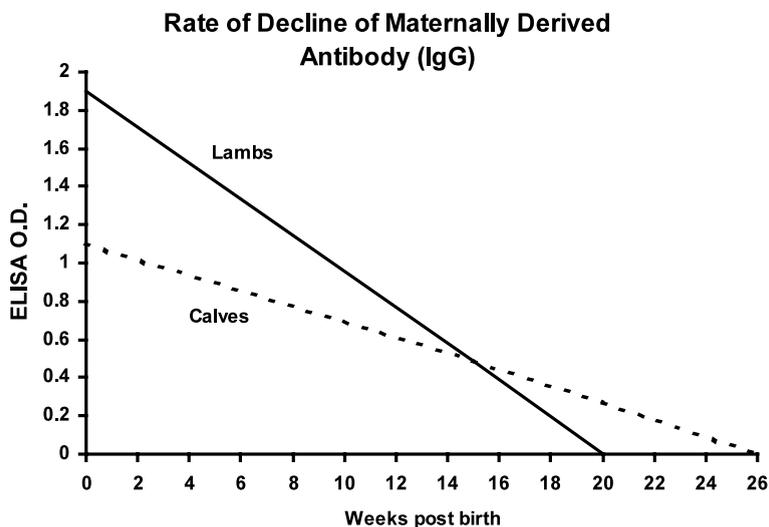**Rate of Decline of Maternally Derived Antibody (IgG)**

Fig. 6. The rate of decline of maternally-derived IgG from lambs and calves that had suckled mothers which had been immunized prior to parturition, as described in Figs. 7 and 8. The half-life of maternally-derived sheep IgG directed against the Eg95 vaccine appears to be less than that for bovines.

programme. Some immunity ($>85\%$) can be maintained in animals after the first two injections, but after the 3rd injection a higher level of immunity can be stimulated, which will be significantly effective for several years. However, to maintain best protection, annual boosting does seems to be the procedure of choice. This needs to be equated against the cost of vaccination, and the desired outcome of using the vaccine. If the label claim is 'Aids in the Control of Hydatid Disease', then an outcome where sheep will resist 85% of infections following two injections needs to be compared with the benefits of a third injection, where sheep will then resist $>95\%$ of natural field infections. The relative effect of various reductions in available biomass of infective cysts needs to be modeled, in conjunction with the various additive effects of numbers of dogs, of various strategic anthelmintic treatment regimes for dogs and of the effects of various education efforts applied to the human population. Torgerson (2002) has created a preliminary model, which indicates that greater success is likely to be achieved if the parasite can be attacked in both hosts of the life-cycle. In both hyperendemic and endemic scenarios a combination of vaccination of intermediate hosts and six-

monthly anthelmintic treatment of definitive hosts is likely to be successful.

7. Maternally-derived immunity

It is essential to determine how much protective antibody is transmitted to the neonate from a vaccinated mother, and how effective it is in protecting the lamb or the calf. Also, it is essential to know what effect does maternally-derived antibody have on the time when the young animal should be vaccinated? It would be useful to be able to vaccinate in the presence of protective maternally-derived antibody so that there was no particular time when the young animal was susceptible to infection from the environment.

Results obtained show that there is significant protection in colostrum from vaccinated sheep or cattle, lasting for about 3 months in lambs and 4–5 months in calves (Fig. 6). Responses of the neonate were perhaps sub-optimal if vaccinated in the presence or absence of maternal antibody at 8 and 12 weeks, but vaccination was optimal if given at 12 and 16 weeks or 16 and 20 weeks (Figs. 7 and 8). Although serology may lead to the conclusion
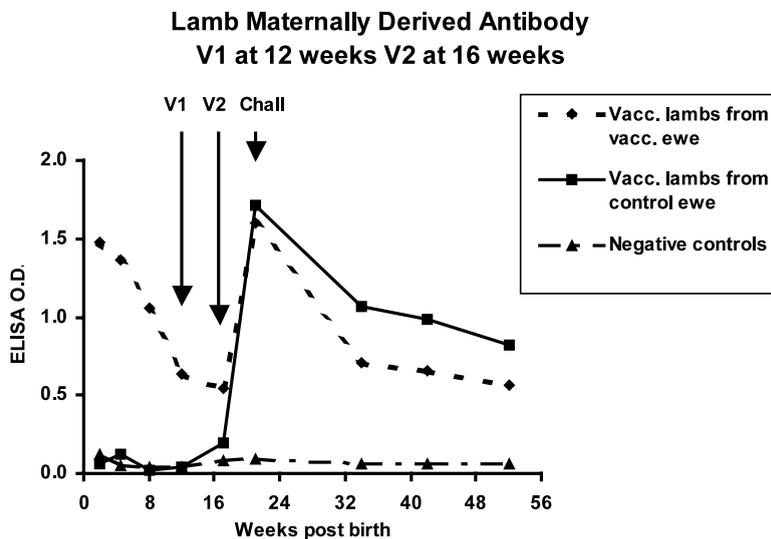
Fig. 7. Maternally-derived antibody levels from a mean of five lambs whose mothers had been immunized with V1 at 3 months and V2 at 4 months of gestation. Five lambs from non-immunised mothers and five from immunized mothers were each given V1 at 16 weeks of age and V2 at 20 weeks of age. A further five lambs were not immunized. All lambs were bled at the points shown in the figure. All lambs were challenged with 4000 freshly-collected *E. granulosus* eggs 4 weeks after V2 and were necropsied 6 months later. Non-immunised lambs had a mean of 571 *E. granulosus* cysts, while both other groups were highly-protected (94 and 96%). The level of maternally-derived antibody at 16 weeks did not interfere with the immune responses. Although maternally-derived antibody was protective against an oral challenge of 4000 eggs at 5 weeks of age (71%), it was not protective at 17 weeks. In another trial, challenge of 1-month-old lambs from vaccinated mothers with *E. granulosus* eggs showed a 98% protection against infection. Number of cysts: lambs from non-vaccinated ewes 45, 140, 152, 176, 190, 371, 384; lambs from vaccinated ewes 0, 0, 1, 2, 3, 5, 19.

that there was some effect due to the presence of the residual protective maternal antibody, this was not apparent in resistance to a challenge infection with *E. granulosus* eggs given 4 weeks after V2.

8. Efficacy against natural challenges with *E. granulosus* eggs

A field trial was set up in Xinjiang Province where natural field challenges were expected. A number of vaccinated and control sheep were necropsied each year. The time when infections took place was determined, based on the size of the cysts found at necropsy. In 3 years there were three major infection periods. A predicted infection period when the animals were very young did not occur. There were three major infection periods, which seemed to coincide with sheep coming back from the summer pastures to the infected environment around the villages (Fig. 3).

The vaccine was effective in protecting against these natural infections.

9. Large-scale field trials

Field trials are necessary in order to show countries that wish to use the vaccine that the vaccine is efficacious and safe and is a suitable control tool to go along with other procedures that might be currently used, but which are not achieving the desired outcome.

After a successful field trial, the epidemiological implications for the client country need to be considered. Different pastoral systems may require different sets of procedures while including vaccination as part of the control program.

If it is not possible to treat dogs regularly with an anthelmintic or to remove excessive dogs because, for instance, of the Buddhist religious belief that dogs are a reincarnation and therefore should not be killed, then it becomes quite

Calf Maternally Derived Antibody
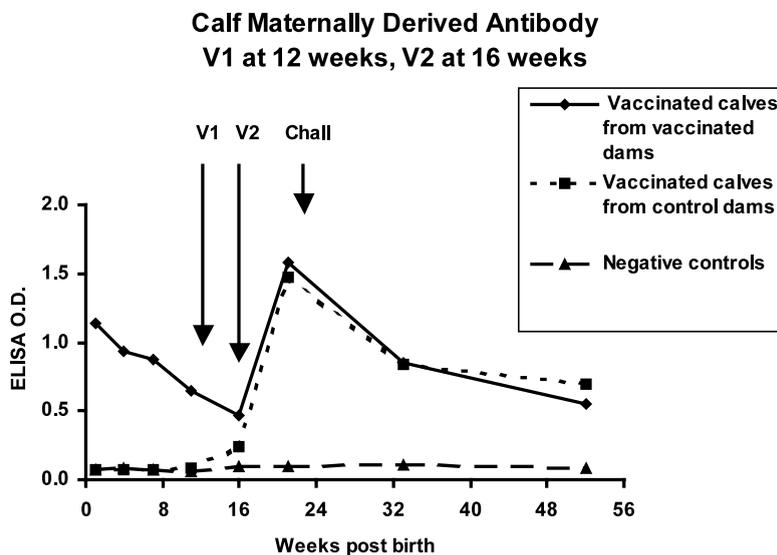## V1 at 12 weeks, V2 at 16 weeks

Fig. 8. Maternally-derived antibody levels from a mean of 5 calves whose mothers had been immunized with V1 at 7 months and V2 at 8 months of gestation. Five calves from non-immunised mothers and five from immunized mothers were each given V1 at 16 weeks of age and V2 at 20 weeks of age. A further five calves were not immunized. All calves were bled at the points shown in the figure. All calves were challenged with 10,000 freshly-collected *E. granulosus* eggs 4 weeks after V2 and were necropsied 9 months later. Non-immunised calves had a mean of 88 *E. granulosus* cysts, while both other groups were fully-protected, and had no cysts. The level of maternally-derived antibody at 16 weeks did not interfere with the immune responses, even though it was still functional at 17 weeks of age (94% protection against an oral challenge with 10,000 eggs).

important to use a procedure which respects these beliefs and traditions. Therefore, apart from education of humans to understand the life-cycle, the vaccine becomes the major tool available for hydatid control.

In China we have set up two large scale field trials in the Provinces of Qinghai and Xinjiang, vaccinating 50,000 and 100,000 lambs to provide large-scale safety information. No problems have been reported. From farm 77, Dao Su, Xinjiang Province, 30 vaccinated and 30 non-vaccinated lambs were necropsied 15 months after vaccination. The animals were shown to have been exposed to two natural field infections: one occurred soon after vaccination, and another about 6 months prior to necropsy. Fifty percent of control animals were infected with 1–50 cysts while only one vaccinated lamb was found with a cyst. For safety determination, a total of 2095 lambs were vaccinated on the farm and the numbers of deaths during and after vaccination were similar to controls. This farm attempts to treat all dogs monthly with an anthelmintic to

Table 2
Monitoring of the progress of the New Zealand hydatid control program

E. granulosus cysts in sheep	
Year	Percentage of sheep, or number of farms found to be infected
1962–63	58% of sheep
1977–78	12% of sheep
1982–83	0.21% of sheep
1984	910 farms
1987	435 farms
1990	3 farms
1996	1 farm

Initially, each meat works was asked to record the infection status of the first six old sheep that were slaughtered each day. After 1980, all hydatid cysts in all classes of stock were recorded at meat inspection, and after 1987 all cysts were submitted for histological diagnosis.

Table 3

Options for hydatid control, and assessment of the likely cost/benefit ratio per year per family of a combined approach using dog-treatments and vaccination

Assumption	Xinjiang (Hutubi County)	Sichuan (Ganzi County)
Family size	5	5
Dogs per family	0.86	2.8
Sheep equivalents per family	13 (sheep or goats)	227 (40 yaks and 27 sheep. A yak is 5 sheep equivalents)
Option 1: monthly treatment of dogs by local veterinarian (80 families/village, vet fees 1 RMB per family each time, praziquantel pills average 1.5/dog at 1 RMB/pill)	(vet. 12 months $\times$ 1 RMB)+(1.5 pills $\times$ 12 months $\times$ 0.86 dogs $\times$ 1 RMB) = 27.5 RMB/year	(vet. 12 months 1 RMB)+(1.5 pills $\times$ 12 months $\times$ 2.8 dogs $\times$ 1 RMB) = 62.4 RMB/year
Option 2: vaccinating livestock (1 RMB per injection and 1 RMB for veterinarian	13 sheep equivalents $\times$ 3 injections within 5 years $\times$ 2 RMB = 16 RMB/year	227 sheep equivalents $\times$ 4 injections within 10 years $\times$ 2 RMB = 182 RMB/year
Option 3: vaccinating livestock and treating dogs twice a year at vaccination times	27.5/6+16 = 20.6 RMB	62.4/6+182 = 192.4 RMB
Returns per family per year for controlling hydatid disease, resulting in a 10% increase in whole-of-life productivity of livestock. Based on 200RMB/sheep at 2 years of age or 1000 RMB/yak at 10 years of age = 100 RMB/year/sheep equivalent	13 sheep equivalents $\times$ 100 = 1300RMB. 10% = 130 RMB	227 sheep equivalents $\times$ 100 = 22700 RMB. 10% = 2270 RMB
Benefit/cost ratio of controlling hydatid disease (excluding any positive human health factors)	130/20.6 = 6.3	2270/192.4 = 11.8
Reference material	Andersen et al. (1991)	Baseline sociological study report (2000, unpublished)

N.B. Option 1 has not proved to be practical and option 2 will not protect humans until all old infected animals have been killed. Option 3 is the recommended program.

protect against cestode infections, but clearly the procedure is not fully effective: hence the need for the vaccine.

10. Conclusion

The hydatid control technology used in New Zealand, of educating the dog-owner about the life-cycle of hydatid disease and treating dogs with an anthelmintic (every 6 weeks for more than 20 years) (Table 2), is often not possible or effective in continental countries, although there are exceptions in Southern America (Thakur, 1999). The reasons for this are many, but include the fact that most countries are not geographically isolated so non-treated dogs can enter the environment. Also it is very difficult to effectively treat dogs with anthelmintic every 4 or 6 weeks for such a long

period of time. It was demonstrated in Xinjiang Province of China that hydatid control could be reasonably effective if it was heavily supervised by a project champion, there were dedicated people doing the work, and the livestock were not taken to the mountains for 6 months of the year. (Andersen et al., 1991). However, in most parts of the world the opportunity to give dogs very regular anthelmintic treatment is not available. The dogs are too difficult to treat because they are guard dogs and for much of the year are away from easy access by veterinarians. Vaccination can be given by veterinarians when they give other injections to grazing livestock for disease control.

Vaccination of livestock as an alternative control method only requires the veterinarians to visit two times each year, and while the veterinarian is visiting, the dogs can also be treated at little additional cost.

One visit by the vet should take place when animals return from Summer pastures, preferably after animals have been killed for Winter food, but before snow makes travel impossible.

In the Northern Hemisphere, November/December would be the months of choice, and this is also a good time to give the first vaccination(s) to animals born during the Summer, and to vaccinate older animals while they are well-fed and able to make a good immune response to the vaccine.

The other visit by the veterinarians should take place in early Spring, after the deaths from late Winter snow-falls. Animals born during the Winter should be vaccinated at this time (March/April), and dogs treated.

The two dog-treatment times (November/December and March/April) coincide with the periods when dogs have the greatest chance of being infected with hydatid parasites (after the autumn kill of livestock, and after the late-winter die-off of starved or cold-stressed animals).

Although a single immunization has been shown to induce a useful degree of protection, where possible it is best to give two initial injections, one month apart. If it is possible for veterinarians to stay in the field for 2 months in November/December and March/April, in order to give the two injections, a more rapid onset of full protective immunity will initially be achieved than if the injections are given 6 months apart.

Putative costings and benefit/cost ratios are shown in Table 3.

A benefit/cost assessment of hydatid control using vaccination and strategic dog treatments, disregarding any benefits to human health, but using a figure of 10% increase in whole of life productive performance of grazing animals, shows a positive result that increases in proportion to the number of animals a family owns.

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