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HEARTWATER IN ANGORA GOATS. I. IMMUNITY SUBSEQUENT TO ARTIFICIAL INFECTION AND TREATMENT

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ABSTRACT

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This study confirmed reports that Angora goats are highly susceptible to *Cowdria ruminantium* and showed that immunization of this breed against heartwater may be difficult and hazardous. It was found that if goats were treated on the 2nd or 3rd day of the febrile reaction following the intravenous inoculation of the heartwater agent, few animals survived the infection. If, on the other hand, treatment was instituted on the 1st day of the reaction, the chances of survival were good, but the immunity of the goats to subsequent challenge was poor.

INTRODUCTION

The Angora goat industry in the Republic of South Africa is well established and of considerable economic importance, but reports from the Eastern Cape of losses as high as 10% due to heartwater pose a real hazard to the industry and call for research on the reasons for the high mortality from this disease in Angoras.

Compared with the large number of reports on the disease in cattle and sheep, only a limited number on heartwater in goats can be traced in the literature. Apart from mere reports of mortalities from heartwater in goats in the Gold Coast (Hughes, 1953), Sudan (Karrar, 1960) and Somalia (Evans, 1963), Ilemobade (1976) in Nigeria reported on the use of locally bred goats in the most comprehensive study so far on heartwater in goats.

There are only a few references to heartwater in the Angora goat. Poole (1962) studied the effects of "block" treatment in the immunization of Angora crossbred goats against heartwater and Erasmus (1976) compared the reactions of Angora goats to 2 different batches of sheep blood infected with the heartwater agent. Gruss (1981) advocated the periodic treatment of Angora goats exposed to natural tick infection as a control measure against heartwater. These and other unpublished reports stress the high susceptibility of the Angora goat to heartwater.

MATERIALS AND METHODS

Experimental animals

The experimental animals consisted of 32 4–6 tooth, castrated males (kapaters) and 24 adult ewes. Some of these, obtained from the Grootfontein Agricultural College, Middelburg, Cape, a region free from the heartwater vector, *Amblyomma hebraeum*, had been bred and raised at the College, but other originated from the Angora Research Station, Jansenville, where the vector does occur (Dr Leonie Jordaan, personal communication, 1982).

Experimental procedure

Infection with Ball 3 strain of C. ruminantium

Two groups of 24 and 26 goats each were inoculated intravenously with 5 mℓ of sheep blood infected with the Ball 3 strain of *C. ruminantium*, issued as a vaccine by the Veterinary Research Institute, Onderstepoort. Early morning temperatures of the animals were recorded and the course of the infection was subsequently blocked by the intramuscular administration of a long-acting preparation of oxytetracycline*. The goats in one group, consisting of adult ewes, were treated at a dosage level of 20–40 mg/kg live mass on the 2nd or 3rd day of the febrile reaction, and again 3 days later, if the animal was still alive. Two goats in this group were left untreated as controls. The animals in the other group, consisting of kapaters, were treated on the day that the 1st rise in body temperature occurred. If it was considered necessary, the animals in this group were treated a 2nd time. Two animals in this group were also left untreated as controls.

All animals that did not react to the inoculum were given a 2nd infective inoculum 1 month later.

Infection with mouse-adapted strain

Six kapaters were inoculated with 5 mℓ of sheep blood infected with the mouse-adapted strain of *C. ruminantium* (Du Plessis, 1982 b). The infected blood was tested for infectivity and for the absence of contaminating micro-organisms, then stored in liquid nitrogen as previously described for the Ball 3 strain (Du Plessis, 1982 b). These goats were not treated.

Additional controls

Eight adult Merino wethers were inoculated in a similar manner with the Ball 3 strain inoculum used to infect the goats. The sheep were treated with tetracycline on the 4th day of the febrile reaction at a dosage level of 20 mg/kg body mass.

Challenge with field strain

At intervals, varying from 107–250 days after the artificial infection, the goats and control sheep were challenged by inoculating them intravenously with 10 mℓ of sheep blood infected with a field strain of *C. ruminantium*. The strain was isolated from an Angora goat from the Messina district of the Northern Transvaal where serious mortalities caused by heartwater were experienced in Angora goats introduced from the Eastern Cape. The strain was passaged several times in sheep and the infected blood was then collected, tested and stored as described above. The early morning termperatures were again recorded and the infection allowed to run its course without treatment.

Pathology

All the animals that died or were killed *in extremis* were autopsied and the tissues of some of them used for clinicopathological, histopathological and ultrastructural studies (Part 11 of this study).

Serology

Pre- and post-infection serum samples as well as samples collected on the day when the goats were challenged, were subjected to the indirect-fluorescent-antibody (IFA) test. Antigen slides were prepared as previously described (Du Plessis, 1982 a), stored at −18°C and fixed in methyl alcohol immediately before use. Serial tenfold serum dilutions were tested and commercial anti-goat fluoresceine-conjugated immunoglobulin* used.

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* Liquamycin/LA, Pfizer

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RESULTS

Reactions to infection

The reactions of the goats and sheep to both the infective and challenge inocula were arbitrarily divided into 4 categories as previously described (Du Plessis & Bezuidenhout, 1979). The animals exhibiting reactions in Categories I and II when challenged were regarded as susceptible and those with reactions in Categories III and IV as immune.

It can be seen from Table 1 that 18 out of 22 goats treated on the 2nd or 3rd day of the reaction showed Categories I and II reactions to the first infective inoculum. The other 4 reacted only after the 2nd inoculation. In the other group (Table 2), treated on the day when the febrile reaction commenced, the reactions of 7 goats fell within Categories I and II, those of 15 others within Category III and 2 animals failed to react at all, even after a 2nd infective inoculum.

Excluding the day of onset of the febrile reaction of Goats 41 and 46, the average incubation period recorded was 12,4 days. In the group treated on the 2nd or 3rd day of the febrile reaction, the average maximum temperature recorded was 41,6°C, and in the group treated on the 1st day of the febrile reaction, 40,5°C. It is therefore evident that treatment on the day when the febrile reaction commenced inhibited the reaction.

It can be seen from Tabel 3 that 5 out of 6 goats, infected with the mouse-adapted strain of *C. ruminantium,* developed severe reactions, 3 of them died and 2 recovered without treatment. One of them had a mild reaction and also recovered.

Survival after treatment

Only 4 out of 24 goats treated on the 2nd or 3rd day of the febrile reaction survived (Table 1), while all except one (Goat 30) of those that were treated on the 1st day of the reaction survived (Table 2). Even those animals in the former group that were treated at double the recommended dosage rate died, as well as 8 goats given a 2nd treatment. The 4 that survived in this group were all treated twice, whereas in the other group a 2nd treatment was considered necessary in only 5 out of the 22 goats that reacted.

Resistance to challenge

It is evident from Table 1 that 3 out of the 4 goats that had survived the infection were immune and the 4th goat was susceptible when they were challenged 107–205 days later. On the other hand (Table 2), 13 out of 22 survivors treated on the 1st day of the reaction were immune and 9 susceptible when they were challenged 107–250 days after recovery from the artificial infection.

There was no correlation between the severity of the febrile reaction to the primary infection and the outcome of the challenge inoculation. Both animals that failed to react to 2 successive infective inocula (Goats 32 and 38) were also fully immune when they were challenged 250 days later.

Likewise, there was no correlation between the tetracycline dosage level used at the time of the artificial infection of the goats and the severity of the reaction that followed, on the one hand, and their eventual immunity to challenge on the other. That is, treatment at a higher dosage level of 30–40 mg/kg was not necessarily followed by a Category III reaction and several animals (Goats 28, 29, 36, 40, 44, 45, 47 & 48), treated at a lower dosage level, also developed Category III reactions. Furthermore, some of these animals (Goats 28, 29 & 40) were resistant to challenge, whereas others (Goats 36, 44, 45, 47 & 48) had no immunity.

Two out of 3 animals, challenged with the field strain after they had recovered from infection with the mouse-adapted strain, proved to be fully susceptible, whilst the other was immune (Table 3).

Controls

All 4 goats that were infected and then left untreated developed severe reactions, and either died or were killed *in extremis*. All 8 control sheep reacted strongly to the Ball 3 sheep blood and all 8 were immune when they were challenged with the Messina field strain.

IFA response

The reciprocals of the titres recorded with the IFA test are given in Tables 1, 2 and 3. The endpoint of the reaction was taken as the highest serum dilution at which specific fluorescence occurred. This point could be readily determined with the higher dilutions, but was often difficult at the 1:10 dilution because of intense, non-specific fluorescence of the mouse-derived cells containing the antigen. A serum that gave a negative reaction at a dilution of 1:10 was considered negative.

Low levels of antibody were found in the pre-infection sera of 6 goats treated on the 2nd or 3rd day of the febrile reaction. Five of them died in spite of the serological evidence that they had previously been infected with *C. ruminantium,* and in spite of treatment. Only one animal (Goat 21) survived and it was also found to be resistant to subsequent challenge. The pre-infection serum of another 9 animals, treated on the 1st day of the febrile reaction, were also found positive, and all except one (Goat 30) survived.

The serological response of the goats to the infective inoculum varied considerably from totally negative reactions in 8 goats, treated on the 1st day of their reaction to the Ball 3 strain (Table 2), to extremely high titres in 2 out of 3 untreated goats infected with the mouse-adapted strain (Table 3). Since the 8 goats, the sera of which gave negative IFA reactions, and 2 other animals (Goats 47 & 48) with extremely low titres, had febrile reactions that fell within Categories III and IV, and since most of the other goats had titres of 1:100 and higher in response to febrile reactions in Categories I and II, it would appear that the antibody response is directly related to the severity of the reaction to infection.

All the goats, the post-infection sera of which were positive, were also serologically positive when they were challenged 3–8 months later. The febrile reactions of 8 out of 11 goats that were serologically negative or that had only trace amounts of antibody (titres of 1:10) when challenged, fell within Categories III and IV, and those of the other 3 within Categories I and II. On the other hand, 5 out of 10 goats with titres of 1:100 and higher showed Categories I and II and the other 5 Categories III and IV reactions. There was, therefore, no correlation between the levels of antibody at the moment of challenge and the resistance of the goats to challenge.

DISCUSSION

The Angora goats used in this experiment proved to be highly susceptible to heartwater. They reacted severely to infection with both the Ball 3 and the mouse-adapted strains of the heartwater agent, and unless they were treated at the very onset of the febrile reaction, they invariably succumbed to the disease. Goats in general are known to be susceptible to heartwater, and serious outbreaks have been reported from Somalia (Evans, 1963) and the Sudan (Karrar, 1960). Whereas local breeds of goats in the Gold Coast were found to be resistant, the crosses with British Alpine goats proved to be highly susceptible (Hughes, 1953). Angora-Afrikander-cross goats were also found to be highly susceptible and

TABLE 1 Febrile reactions to infection and challenge of Goats No. 1–22 treated on the 2nd or 3rd day of the reaction to the infective inoculum and of untreated controls

Goat No	Febrile reaction to infection				Treatment		Outcome	Febrile reaction to challenge				Outcome	Inter-[1] val (days)	Reciprocals of IFA titres		
	Day of onset	Duration (days)	Max. temp. °C	Category	First	Second		Day of onset	Duration (days)	Max. temp. °C	Category			Preinfection	Postinfection	At challenge
1	14	5	42	I	3/40[3]	6/30	Died							—		
2	12	3	41,7	I	3/40	—	Died							—		
3	11	4	41,8	I	3/40	—	Died							—		
4	11	5	41,8	I	3/40	—	Died							—		
5	11	7	41,6	I	3/40	6/40	Survived	—	—	—	IV	Survived	175	—	1 000	100
6	11	3	41,9	I	3/40	—	Died							—		
7	11	7	41,3	II	3/30	6/40	Survived	8	7	41,9	II	Survived	107	—	100	100
8	15	5	41,1	I	2/40	5/40	Died							—		
9	11	6	41,6	I	3/40	6/40	Died							—		
10	12	8	41,5	I	2/40	5/40	Died							—		
11	11	4	41,4	I	3/40	—	Died							—		
12[2]	13	4	41,6	I	3/40	—	Killed *in extremis*							100		
13	11	6	41,6	I	3/40	6/40	Died							—		
14	12	4	41,5	I	2/40	5/40	Died							100		
15	14	5	40,8	I	2/40	5/40	Died							—		
16	11	4	41,4	I	3/40	5/40	Died							—		
17	13	4	41,4	I	3/40	—	Died							—		
18[2]	11	5	41,7	I	3/40	—	Died							100		
19	13	4	41,7	I	2/40	—	Died							100		
20[2]	12	7	42	I	3/30	6/30	Survived	—	—	—	IV	Survived		—	10	10
21[2]	13	8	42	I	2/20	5/20	Survived	14	5	40,3	III	Survived	205	100	1 000	1 000
22	14	4	42	I	3/40	—	Died									
23	11	7	41,9	I	Control		Killed *in extremis*									
24	13	7	42	I	Control		Killed *in extremis*									

[1] Interval in days between infection and challenge

[2] Goat 12 failed to react to the first infective inoculum, but reacted to the second 4 weeks later

[3] 3/40 = Goat 1 was treated on the third day of the febrile reaction at a dosage rate of 40 mg/kg body mass

TABLE 2 Febrile reactions to infection and challenge of Goats No. 25–48 treated on the first day of the reaction to the infective inoculum and of untreated controls

Goat No	Febrile reaction to infection				Treatment		Outcome	Febrile reaction to challenge				Outcome	Interval (days)	Reciprocals of IFA titres		
	Day of onset	Duration (days)	Max. temp. °C	Category	First	Second		Day of onset	Duration (days)	Max. temp. °C	Category			Pre-infection	Post-infection	At challenge
25	12	6	41,6	I	1/40	4/40	Survived	16	6	40,9	II	Survived	175	—	1 000	100
26	12	7	41,2	II	1/30	4/40	Survived	—	—	—	IV	Survived	175	—	100	10
27	14	4	40,6	III	1/30	4/40	Survived	16	11	40,4	I	Died	107	100	1 000	(4)
28	13	8	40,4	III	1/20	4/40	Survived	16	7	39,7	III	Survived	157	—	1 000	(4)
29	14	6	40,6	III	1/20	—	Survived	16	6	39,3	III	Survived	157	100	1 000	(4)
30	13	4	41,2	I	1/40	4/20	Died							10		
31	11	7	41,1	III	1/30	—	Survived	10	7	41,3	II	Survived	250	—	100	100
32[1]	—	—	—	IV	—	—	Survived	—	—	—	IV	Survived	250	—	—	—
33	13	8	40,8	II	1/30	—	Survived	13	5	40,1	III	Survived	250	10	100	100
34	13	7	39,8	III	1/30	—	Survived	14	4	39,5	III	Survived	211	10	—	—
35	13	4	41,6	II	1/20	—	Survived	—	—	—	IV	Survived	250	100	1 000	1 000
36	13	5	40,2	III	1/20	—	Survived	11	3	42	I	Died	211	—	—	—
37	12	7	41,2	II	1/20	—	Survived	15	3	41	III	Survived	250	—	100	10
38[1]	—	—	—	IV	—	—	Survived	—	—	—	IV	Survived	250	—	—	—
39[3]	13	9	40	III	1/20	—	Survived							100		
40	13	5	39,8	III	1/20	—	Survived	10	3	39,6	III	Survived	250	10	100	100
41	26	5	40,1	III	1/30	—	Survived	7	4	39,3	III	Survived	211	—	—	—
42	13	5	39,2	III	1/20	—	Survived	—	—	—	IV	Survived	211	—	—	—
43	13	5	40,6	III	1/30	—	Survived	—	—	—	IV	Survived	250	—	1 000	100
44[2]	10	2	40,2	III	1/20	—	Survived	8	4	42	I	Died	250	—	—	—
45	11	7	41,1	II	1/20	—	Survived	13	4	41,5	I	Died	250	—	1 000	1 000
46	26	5	39,7	III	1/30	—	Survived	10	4	41,5	I	Died	211	—	—	—
47	15	1	39,6	III	1/20	—	Survived	10	4	42	I	Died	250	10	10	100
48	13	4	40,1	III	1/20	—	Survived	10	7	42	I	Died	211	—	10	100
49	11	4	42	I	Control		Killed *in extremis*									
50	12	4	41,3	I	Control		Died									

[1] Goats 32 and 38 failed to react to either of the first or second infective inocula

[2] Ditto (2) in Table 1

[3] Goat 39 was not challenged

[4] Serum sample not available

TABLE 3 Febrile reactions of Goats No 49–54 infected with the mouse-adapted strain of *C. ruminantium* and challenged with the Messina field strain

Goat No	Febrile reaction to infection				Outcome	Febrile reaction to challenge				Outcome	Interval (days)	Reciprocals of IFA titres	
	Day of onset	Duration (days)	Max. temp. °C	Category		Day of onset	Duration (days)	Max. temp. °C	Category			Pre-infection	At challenge
49	11	8	41,8	II	Survived	12	6	39,5	III	Survived	117	—	$<10^5$
50	11	4	42	I	Died							—	
51	8	7	41,9	I	Died							—	
52	16	6	42	I	Died							—	
53	11	10	41,9	I	Survived	12	5	41,3	I	Died	90	—	$<10^5$
54	25	4	40	III	Survived	12	3	42	I	Died	90	—	10

TABLE 4 Febrile reactions of control sheep infected with the Ball 3 strain and challenged with the Messina field strain

Sheep No.	Febrile reaction to infection				Outcome	Febrile reaction to challenge				Outcome
	Day of onset	Duration (days)	Max. temp. °C	Category		Day of onset	Duration (days)	Max. temp °C	Category	
1	10	7	41,2	II	Survived	—	—	—	IV	Survived
2	10	6	41,5	II	Survived	—	—	—	IV	Survived
3	9	5	41,4	II	Survived	—	—	—	IV	Survived
4	9	5	41,4	II	Survived	13	3	40,5	III	Survived
5	9	5	42	II	Survived	—	—	—	IV	Survived
6	9	5	42	II	Survived	—	—	—	IV	Survived
7	9	6	42	II	Survived	12	5	39,4	III	Survived
8	9	5	42	II	Survived	14	4	39,4	III	Survived

purebred Angoras even more susceptible than the Angora-Afrikander-crosses, because more extensive treatment was found necessary to save the former from fatal infection (Poole, 1962).

One of the main purposes of this investigation was to determine whether Angora goats that have made a drug-aided recovery from an artificial infection of heartwater are immune to subsequent challenge. In previous studies on Angoras or Angora cross-breds, immunity to challenge was either not determined (Erasmus, 1976), or conclusive evidence of its efficacy could not be obtained (Poole, 1962).

In this study a serious dilemma confronted us. On one hand, it was found that, unless treatment was given on the 1st day that the temperature of the goats showed a definite rise, the majority died, irrespective of the dosage level used or the number of treatments given. On the other hand, almost 50% of goats that had recovered after treatment on the 1st day of the febrile reaction were found to be susceptible to challenge.

The immunization of Angora goats against heartwater therefore presents a problem. Treatment early enough in the febrile reaction to prevent a fatal outcome of the infection appears to inhibit the reaction to such an extent that an adequate immunity fails to develop. There is little doubt that in heartwater, immunogenicity parallels pathogenicity or, in the present context, the full development of the pathological process. It has constantly been found that the more severe the reaction elicited by a particular infective inoculum of the heartwater agent in sheep and cattle the stronger their immunity to subsequent challenge (Du Plessis, unpublished observations, 1980). This may explain why the drug-aided suppression of a reaction in the goats results in an inadequate immunity.

Treatment during the incubation period of an artificial infection, the so-called "block" method of immunization, is also not satisfactory, since Poole (1962) found that significant numbers of goats, blocked on the 5th and 6th day after infection, had to be re-treated. Although there may be less risk of losing goats by this method of immunization, there is as yet no conclusive evidence that an adequate immunity develops in animals that have to be re-treated.

Apart from failure in this study to effect a drug-aided recovery, followed by a good immunity, there were also indications that the immunity of Angora goats against heartwater is both of short duration and inadequate, even after outspoken reactions to the infective inoculum. It was found that several goats that had recovered from Category I or II reactions to infection, contrary to what was expected, reacted again when they were challenged and 1 even succumbed to the challenge. These breaks in immunity occurred as early as 4–8 months after artificial infection. If it is borne in mind that sheep were found to be immune when they were challenged 4 years after infection without having been re-infected during this period (Neitz, Alexander & Adelaar, 1947), it would appear that the immunity of Angora goats to *C. ruminantium* is of short duration.

Furthermore, serological evidence obtained with the IFA test, showed that 15 of the goats used in this experiment had been infected with the heartwater agent prior to their arrival at this institute. Although 3 of these animals failed to react to the 1st infective inoculum, suggesting protection against the heartwater agent, they reacted severely to the 2nd inoculation. All the others were fully susceptible to the 1st inoculation. These observations suggest that the immunity of Angora goats against heartwater, even after their recovery from a severe reaction or after natural tick-infection, is often inadequate and of short duration.

The rapid, fatal course of the 2 goats in each group left untreated as controls proves that the difference in survival and eventual immunity between the 2 groups of goats is not attributable to their age and sex differences. The equally acute course of 5 out of 7 young kapaters that died when they were challenged, in spite of having made a drug-aided recovery from the primary infection, supports this conclusion.

The serological response of the goats to infection with *C. ruminantium*, as determined with the IFA test, showed great variation. Trace amounts of antibody to titres of 1:1000 showed little correlation either with the severity of the reaction to the initial infection or with the degree of resistance to subsequent challenge. There were even 8 goats that were serologically negative 1–2 months after infection; when they were challenged, they were still negative and yet only 3 of them proved to be susceptible.

Treatment early in the febrile reaction may have been responsible for the low levels of antibody detected in many cases. All 8 animals that were serologically negative after recovery had been treated on the 1st day of the febrile reaction, whereas 2 out of the 4 surviving goats, treated on the 2nd or 3rd day, had high antibody titres. Exceptionally high titres in 2 goats that had recovered without treatment from infection with the mouse-adapted strain suggest that severe reactions, unaffected by treatment, result in high levels of antibody. Sheep that reacted severely to infection with either the Ball 3 or the mouse-adapted strain and treated late in the febrile reaction, also had high levels of antibodies (Du Plessis, 1982 b).

Similar to what was found in cattle (Du Plessis, 1982 a; Du Plessis & Bezuidenhout, unpublished observations, 1982), there was in this case no correlation between the presence of antibodies detected with the IFA test and their resistance to challenge. Thus, 6 goats that were serologically positive when challenged proved to be susceptible, whereas 5 other serologically negative animals were found to be immune.

Two out of 3 goats that had recovered from infection with the mouse-adapted strain succumbed to challenge with the field strain. The resistance of the control sheep to challenge with the latter strain after recovery from infection with the Ball 3 strain proved that these 2 strains are immunologically indistinguishable. The absence of cross-immunity between the mouse-adapted and the challenge strain in this study, therefore, corresponds to the susceptibility to challenge with the Ball 3 strain of sheep immune to the mouse-adapted strain (Du Plessis, 1982 b) and cannot be regarded as additional evidence of the immunological deficiency of the Angora.

In the case of the goats infected with the Ball 3 strain, however, the similarity between it and the challenge strain is significant, since it proves that the collapse in the immunity of the goats when challenged could in all probability be attributed to the immunological incompetence of the Angora and not to an immunologically different challenge strain.

REFERENCES

DU PLESSIS, J. L., 1982 a. The effect of intensive tick control on the immunity of cattle to heartwater. *Proceedings of Symposium on Ectoparasites of Cattle*, Pretoria, 1982, 18–27.

DU PLESSIS, J. L., 1982 b. Mice infected with a *Cowdria ruminantium*-like agent as a model in the study of heartwater. D.V.Sc. Thesis, University of Pretoria.

DU PLESSIS, J. L. & BEZUIDENHOUT, J. D., 1979. Investigations on the natural and acquired resistance of cattle to artificial infection with *Cowdria ruminantium*. *Journal of the South African Veterinary Association*, 50, 334–338.

ERASMUS, J. A., 1976. Heartwater: the immunisation of Angora goats. *Journal of the South African Veterinary Association,* 47, 143.

EVANS, S. A., 1963. Heartwater (Rickettsiasis) in Northern Somalia. *Bulletin of Epizootic Diseases of Africa,* 11, 232–233.

GRUSS, B., 1981. A practical approach to the control of heartwater in the Angora goat and certain sheep breeds in the Eastern Cape coastal region. *Proceedings of International Congress on Tick Biology and Control,* Grahamstown, 1981, 135–136.

HUGHES, M. H., 1953.A rickettsial disease of goats in the Gold Coast. *Annals of Tropical Medicine and Parasitology,* 47, 299–303.

ILEMOBADE, A. A., 1976. Study of heartwater and the causative agent, *Cowdria ruminantium* (Cowdry, 1925), in Nigeria. Ph.D. Thesis, Zaria.

KARRAR, G., 1960. Rickettsial infection (heartwater) in sheep and goats in the Sudan. *British Veterinary Journal,* 116, 105–114.

NEITZ, W. O., ALEXANDER, R. A. & ADELAAR, T. F., 1947. Studies on immunity in heartwater. *Onderstepoort Journal of Veterinary Research,* 21, 243–249.

POOLE, J. D. H., 1962. Flock immunisation of sheep and goats against heartwater. Part II. Preliminary experiments on flock immunisation of goats. *Journal of the South African Veterinary Association,* 33, 357–362.