

## Differences in the Egg Morphology and Certain Biological Characteristics of Some African and Middle Eastern Schistosomes, Genus *Schistosoma*, with Terminal-Spined Eggs \*

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*There is some confusion regarding the differentiation of African and Middle Eastern schistosomes with terminal-spined eggs. In an attempt to clarify the situation, the author has separated the members of the genus Schistosoma that have terminal-spined eggs into three broad groups and five species on the basis of egg morphology and certain biological characteristics.*

*The groups are : the haematobium group, with one species (S. haematobium); the bovis group, with three species (S. bovis, S. matthei and S. leiperi); and the intercalatum group, with one species (S. intercalatum). Further species separation is not thought to be justified yet, and reasons are given for considering S. capense and S. curassoni as synonymous with S. haematobium and S. matthei respectively.*

Numerous terminal-spined-egg schistosomes of the genus *Schistosoma* have been described from Africa since Bilharz's discovery in 1851 of *Schistosoma haematobium* in man and Sonsino's finding in 1876 of *Schistosoma bovis* in cattle. Not only have some descriptions been based on rather scanty evidence, but considerable confusion also exists regarding the identification and differentiation of these schistosomes.

Identification is generally based on the morphological characteristics of the eggs and, although reasonably constant and well-defined differences might be expected to occur between the eggs of the various species, this is not in fact so; to add to the difficulties, well-recognized biological differences

dependent on the relationship between the schistosomes and the snail host occur within a single schistosome species. Further, there are no anatomical features which readily distinguish the adults except the morphology of the intra-uterine eggs.

Egg morphology, although possibly often unsatisfactory, is undoubtedly the simplest means of identification and can always be taken in conjunction with biological data available from the field and the laboratory. With time, identification and differentiation might well be based on development, adult taxonomic, serological or some other characteristics, but at the moment there seems to be a great lack of data of this kind for comparative purposes. Little account has therefore been taken here of what little evidence there is and in this paper the members of the genus *Schistosoma* with terminal-spined eggs that occur in Africa and the Middle East have been separated into three broad groups and five species on the basis of egg morphology and certain biological characteristics.

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## MATERIALS AND METHODS

## COLLECTIONS

*Adults*

Adult schistosomes were collected from the liver or mesenteric veins of definitive hosts as soon after death of the host as possible, either in the laboratory, in abattoirs or in the field. The worms were collected from larger animals such as cattle, sheep and antelopes by holding the warm mesentery up against the light and looking for the worms in the mesenteric veins. They are generally easily found unless the mesentery becomes cold, when the fat solidifies. The vein was incised above or below the worms and they were gently pushed through the cut vein and placed in normal saline. After a variable period, 12-24 hours depending on the temperature, the saline was decanted, the worms washed in saline and a 5% formol saline solution added in which the worms were immediately shaken for about two minutes to separate the males and females and to obtain as much extension as possible. They were left for at least 24 hours in the formol saline before being transferred to 70% alcohol with 5% glycerol added. For examination, the alcohol was evaporated off slowly under a watch glass over a five- to six-day period, leaving the worms in glycerol ready for examination. There was no apparent shrinking of the intra-uterine eggs after evaporation of the alcohol and the worms could thereafter be kept in glycerol.

*Eggs*

Eggs were collected from various tissues and excreta of the definitive hosts either in the field, laboratory or abattoirs and preserved in 5%-10% formol saline as soon as possible.

*Human urine.* Urine was sedimented by gravity for 10-15 minutes, the supernatant was decanted and the deposit poured into a Petri dish; the eggs were swirled into the centre and pipetted off, with as little urine as possible, into excess 5% formol saline and again allowed to sediment by gravity. The eggs were then collected by again pouring off the supernatant and repeating the process in the Petri dish. They were kept in formol saline for future examination.

*Faeces.* Fresh faeces was placed directly into a wide-mouthed bottle and covered with 5%-10% formol saline, well shaken and left for a few hours before sieving, repeated washing, sedimenting and decanting prior to egg collecting in a Petri dish under a wide-field stereoscopic microscope. Eggs were subsequently kept in 5%-10% formol saline. It must be pointed out that collection of schistosome eggs from the faeces of domestic animals is an extremely arduous and time-consuming task and one hardly worth embarking upon, even with very heavily infected animals.

*Gut.* Whole portions of the gut of cattle and other animals were opened longitudinally and the contents removed by hand (not with water). The portions of gut were then placed in 5%-10% formol saline in a bottle. Subsequently the mucosa and submucosa were scraped off and ground through a sieve and the eggs collected by resieving and repeated washing and sedimenting.

*Rodent liver.* The whole or half liver was washed in normal saline as soon as the animal was dead and at once mashed through a sieve with 5%-10% formol saline. The eggs were collected by sedimentation, decanting, resieving and examination under a wide-field stereoscopic microscope by swirling them into the centre of a Petri dish. They were kept in formol saline.

## EXAMINATIONS

All observations on extra-uterine eggs were based only on eggs containing a fully developed miracidium. Eggs which were obviously deformed were disregarded.

All microscopic work was done with wet preparations under a supported cover-slip.

It has been shown that the shape and measurements of eggs are not affected significantly by fixation in formol (Porter, 1938; de Meillon, personal communication).

With the exception of the collecting of the *S. leiperi* and *S. intercalatum* material and the *S. haematobium* material from India and Malagasy, all collections, examination, drawings, etc. were done by the author unless otherwise stated.

## RESULTS

The lengths, standard deviations and numbers of extra-uterine eggs together with the definitive host and locus are set out in Fig. 1. Fig. 2 shows data for the intra-uterine eggs. Measurements of extra-uterine eggs are shown in Table 1.

## THE HAEMATOBIMUM GROUP

This group includes *S. haematobium* (Bilharz, 1852) and *S. capense* (Harley, 1864). The extra-uterine eggs are oval, measuring from about 80  $\mu$  to 190  $\mu$  in length, and the spine can usually be differentiated from the body (Fig. 1; Drawings 1-3A; Table 1). Drawing 4 shows intra-uterine eggs, which are smaller, 57  $\mu$ -119  $\mu$  (Fig. 2), but otherwise have the same general shape. The adult parasites inhabit the vesical or mesenteric veins of a very limited range of definitive hosts in nature, with man the only important one; the others are academic curiosities only.

*S. haematobium* (Bilharz, 1852) (Table 1; Fig. 1; Drawing 1)

The morphological characteristics of the eggs of this schistosome from man (Drawing 1) are well known and hardly warrant further description. Classically they are deposited in and excreted from the bladder of man but are found in the gut more commonly than was originally suspected. They are, however, rarely excreted in a viable form in the faeces.

Apart from man, *S. haematobium* has been reported in nature from the bladders of two domestic pigs from Nigeria (Hill & Onabamiro, 1960); four sea-lions (*Zalophus californianus*) from the Cairo zoo, in which the vesical veins were free of worms but schistosome eggs (species unstated) were found in the bladder (Ezzat et al., 1958); one baboon (*Papio* sp.) with a bladder infection and one vervet monkey (*Cercopithecus aethiops*) with a gut infection from Kenya (Nelson et al., 1962); and one rodent (*Otomys tugelensis*) with eggs in the liver and gut from the Eastern Transvaal (Pitchford, 1959a). With the single exception of the *Otomys*, confirmation of the above findings was not attempted by transmission through laboratory animals; in the case of the *Otomys* infection (*Otomys* X liver, Fig. 1; and Drawing 3A), the original identifica-

tion of *S. haematobium* had to be amended to a *S. haematobium/mattheei* hybrid (Fig. 1, *Mastomys* and white mouse ex *Otomys* X; and Drawing 3B). The baboon in Kenya had an infection with both *S. haematobium* and *S. mattheei*-like eggs; the vervet monkey was from an area where *S. mattheei* is known to occur; the Nigerian pigs had probably pure *S. haematobium* infections as had the sea-lions from Egypt if, as is believed today, *S. bovis* does not occur in Egypt. In any case, *S. haematobium* is a parasite with a very limited range of natural definitive host species.

The intermediate hosts are classically snails of the *truncatus* and *forskali* group but not the *africanus* group, and Le Roux (1958), at a laboratory meeting of the Royal Society of Tropical Medicine and Hygiene, stated that he had failed repeatedly "to infect laboratory-bred specimens of *Bulinus* (*Bulinus*) *truncatus* and *B. (B.) coulboisi* with any of the African species [of schistosomes] which have as their intermediaries species of the genus *Bulinus* (*Physopsis*)" but that he had succeeded "in infecting *B. (B.) truncatus*, *B. (B.) coulboisi* and *B. (B.) forskalii* with a strain of *S. haematobium* from Egypt . . . [His] further attempts at infecting *B. (B.) truncatus* from Israel and Egypt, *B. (B.) senegalensis* from Gambia and *B. (B.) forskalii* from Northern Rhodesia with a strain of *S. haematobium* from Nyasaland and Southern Africa, failed to establish infection although the infection was readily established in *B. (Physopsis) africanus* and *B. (P.) globosus*." From these results he deduced "that the common parasite of urinary bilharziasis in Southern Africa must be accepted as a species distinct from *S. haematobium* (Bilharz, 1852)" and suggested "*Schistosoma capense*, as amended".

*S. capense* (Harley, 1864)

This parasite was originally described from Uitenhage in the Eastern Cape Province of South Africa by Harley (1864) as *Bilharzia capensis*. Harley's illustrations of the eggs from the urine of a human being showed typical *S. haematobium*-like ova together with terminal-spined ova of a second schistosome. Today the second schistosome is not considered to be *S. haematobium* or *S. capense*, and Le Roux (1958) stated that "Blackie has suggested that Harley's Fig. 12 [the egg of the second schisto-

FIG. 1  
LENGTHS, MEAN LENGTHS AND STANDARD DEVIATIONS OF EXTRA-UTERINE SCHISTOSOME OVA

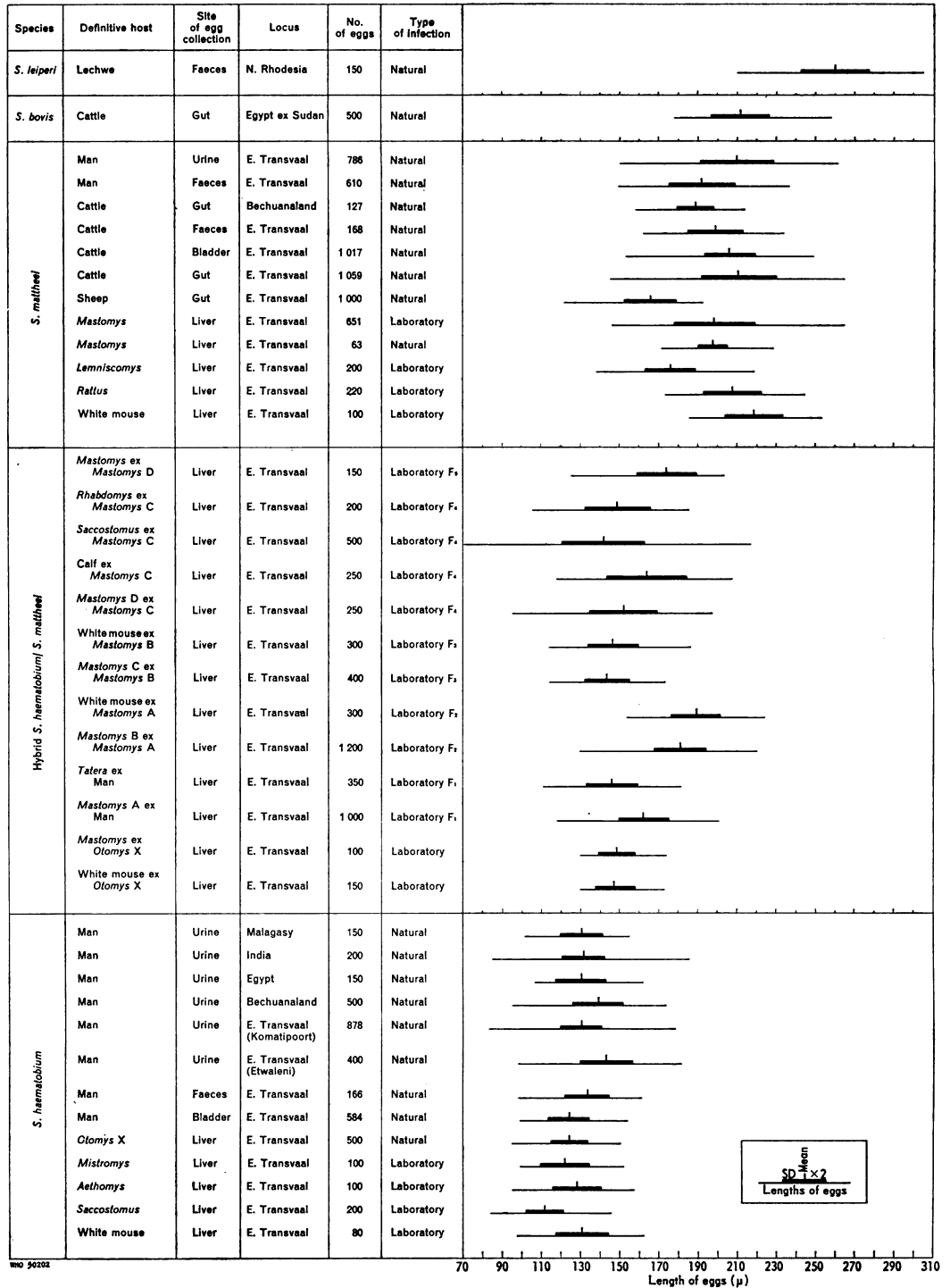
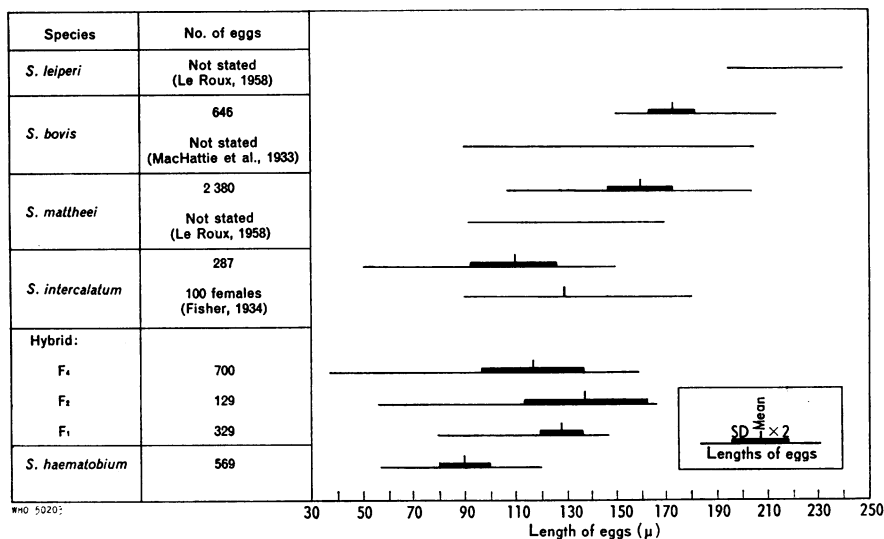


FIG. 2  
LENGTHS, MEAN LENGTHS AND STANDARD DEVIATIONS OF INTRA-UTERINE SCHISTOSOME OVA



some] is that of an egg of *S. mattheei*. The other figured eggs are undoubtedly those of the parasite which is the common causal agent of urinary bilharziasis in Southern Africa . . . Since *B. capensis* has been universally accepted by the authors of medical text-books to be a schistosome, and since the one egg (Fig. 12) has been identified as that of *S. mattheei*, there should be no objection from medical helminthologists to accept the name *Schistosoma capense* (Harley, 1864) as amended here, for the common causal parasite of urinary bilharziasis in South Africa." It is not altogether clear whether he considered South and southern Africa as synonymous. He continued and stated that the ratio "breadth  $\times$  100 length (spine not included) of the eggs from human cases originating from Egypt and the Sudan and from cases from Southern Africa (Transvaal, Southern Rhodesia, Northern Rhodesia, Nyasaland and the southern parts of Belgian Congo) showed that the ratios in the case of *S. haematobium* varied from 32-49. In the majority of eggs the ratios were 35-45. In the case of the species *S. capense* (Harley), as amended, the ratios varied from 33-60 with most of the eggs falling within the ratio 39-50." He also stated that the adults differed from *S. haematobium* in that the ovary was equatorially situated in material from an experimentally infected monkey.

It is thought that this separation of *S. capense* from *S. haematobium* is not justified for the following reasons:

(a) The differences in the morphology and measurements (Table 1, Fig. 1; Drawings 1-3A) of the eggs from various localities do not appear to warrant separation into two species.

(b) A local Nelspruit snail, identified as a member of the *truncatus* group (van Eeden, personal communication), has been found susceptible in this laboratory both to so-called *S. capense* and to *S. mattheei* and was no less susceptible to both these schistosomes than the *Bulinus* (*Physopsis*) sp. of the *africanus* group.

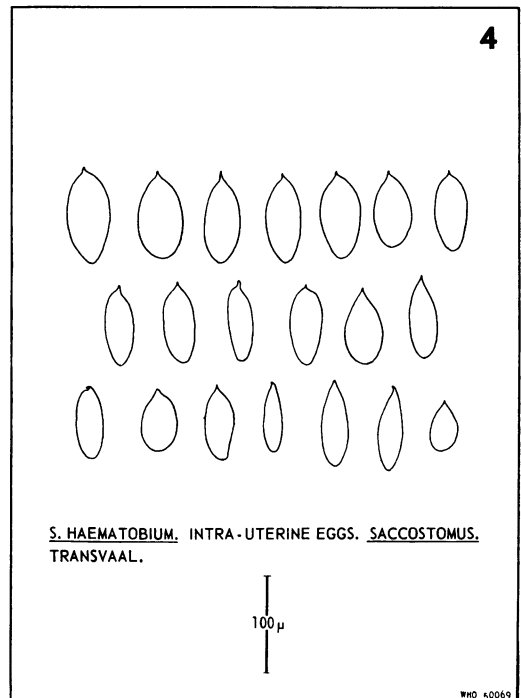
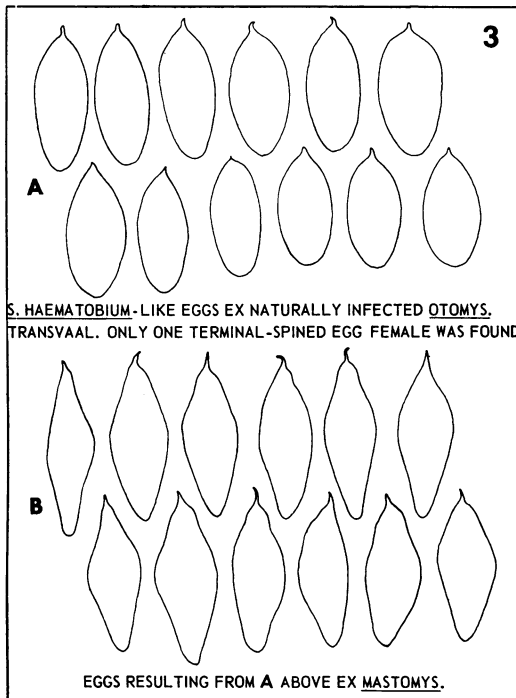
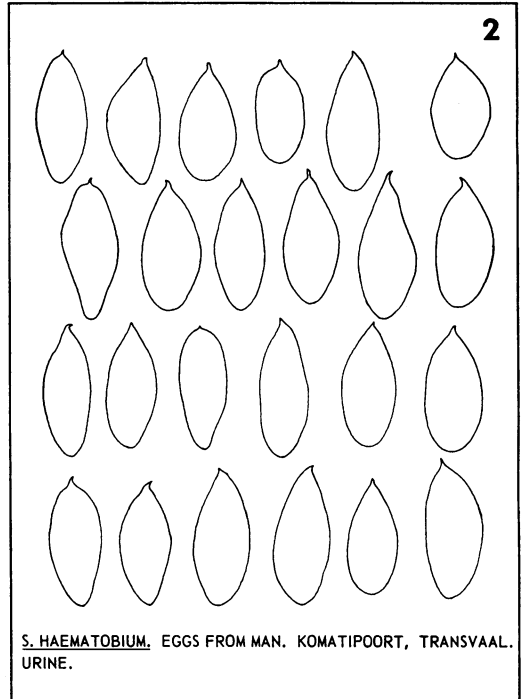
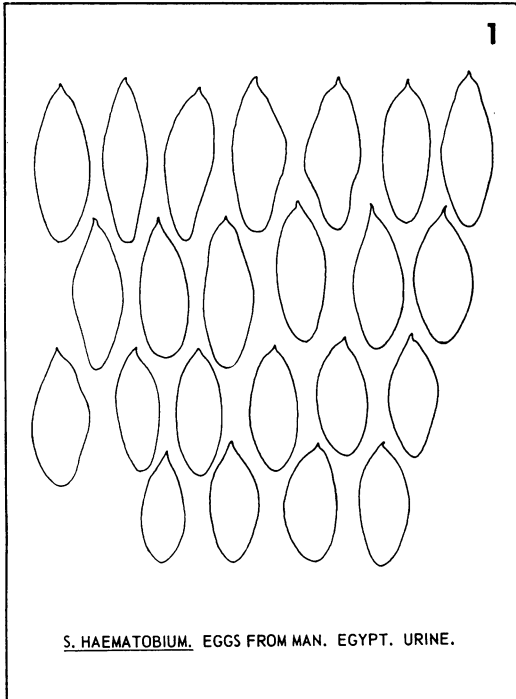
(c) The ovaries of the common causal parasite of human urinary bilharziasis from experimentally infected rodents in this laboratory are not necessarily equatorially situated.

It is felt, therefore, that the name *S. capense* (Harley, 1864) of the causal parasite of human urinary bilharziasis in southern Africa should be regarded as synonymous with *S. haematobium* (Bilharz, 1852) and further that members of the *africanus* group as well as those of the *truncatus* and *forskallii* groups of the genus *Bulinus* Müller as classified by Mandahl-Barth (1958) be regarded as the intermediate hosts of *S. haematobium*.

TABLE 1. MEASUREMENTS OF EXTRA-UTERINE, TERMINAL-SPINED, SCHISTOSOME OVA

Species	Author	Locality	Host	Length ( $\mu$ )			Spine length ( $\mu$ )			No. of eggs
				Range	Mean	SD of mean	Range	Mean	SD of mean	
<i>S. leiperi</i>	Le Roux (1955)	Northern Rhodesia (now Zambia)	Lechwe	210-305 240-300	260	17.9	Not measurable	—	150	
<i>S. bovis</i>	Alves (1949)	Sudan	Cattle { Sheep Cattle Goats }	178-257	211	14.0	3.9-15.8 8.2 (70% not measurable)	3.0	500	
	MachHattie et al. (1933) Khalil (192 )	Iraq		179-232 130-260 160-180	208				500	
<i>S. matthei</i>		Transvaal	Cattle	146-261	211	19.8	1.9-27.6	11.6	1 059	
		Transvaal	Man	146-259	202	20.5	3.9-27.6	13.5	1 396	
		Transvaal	Rodents (various)	146-265	197	20.8	3.9-23.7	11.3	1 507	
		Transvaal	Sheep { Mice Hamster Guinea-pig }	120-194 180-232 170-280	166 200	12.6	1.9-23.7	10.4	1 000	
	Alves (1949) Veglia & Le Roux (1929)	Cape						500		
<i>S. curassoni</i>	Brumpt (1931)	French Sudan (now Mali)	Ox	110-120 (Intra-uterine)					Two females	
<i>S. intercalatum</i>	Fisher (1934)	Congo (Leopoldville)	Man	140-240	175		Up to 20		430	
Hybrid ( <i>S. haematobium</i> / <i>S. matthei</i> )		Transvaal	Rodents (various)	118-202	163	13.5	1.9-19.7	7.6	1 000	
	F <sub>1</sub>	Transvaal	Mastomys	130-221	182	13.5	3.9-23.7	14.9	1 200	
	F <sub>2</sub>	Transvaal	Calf	114-211	163	20.3	1.9-15.8	6.7	2 920	
	F <sub>4</sub>	Transvaal	Saccostomus	72-216	142	21.8	1.9-19.7	9.2	500	
	F <sub>5</sub>	Transvaal	Mastomys	125-203	174	15.5	3.3-23.7	13.7	150	
<i>S. haematobium</i>		Bechuanaland	Man	95-174	139	13.0	1.9-15.8	7.3	500	
		Transvaal	Man	83-182	136	13.6	1.9-19.7	7.0	1 944	
		India	Man	83-187	132	11.8	1.6-10.1	6.3	200	
		Egypt	Man	108-162	131	11.6	1.9-19.7	6.4	100	
		Malagasy	Man	102-160	131	11.6	3.3-13.5	6.7	150	
		Transvaal	Rodents (various)	85-163	122	11.8	1.6-16.9	6.4	980	
		{ W. Africa Sudan Rhodesia }	Man	115-170	142				500	

DRAWINGS 1-4



On the other hand, Lengy (1962) reports that the stage of egg-laying of *S. haematobium* (presumably from Israel) in mice is reached in 35-42 days, whereas Edwards & McCullough (1954) in Ghana, Schwetz (1956) in the Congo (Leopoldville) and work in this laboratory on *S. haematobium* from Transvaal show that egg production is not reached until double this time. (Edwards & McCullough's estimations were based on eggs in the excreta.) It is, however, obvious that further work on the development stages and other aspects of both the northern and the southern *S. haematobium* is urgently needed before more definite conclusions can be reached.

#### THE BOVIS GROUP

This group includes *S. bovis* (Sonsino, 1876), *S. matthei* Veglia & Le Roux, 1929, *S. curassoni* Brumpt, 1931, and *S. leiperi* Le Roux, 1955. The extra-uterine eggs are spindle-shaped or bipolar, about  $120\ \mu$  -  $300\ \mu$  in length (Fig. 1; Table 1), with parallel or nearly parallel sides to the processes (Drawings 5, 7, 8 and 10). Often the spine cannot be differentiated from the body of the egg (Drawings 5 and 10). The intra-uterine eggs, apart from being smaller, with a length of  $90\ \mu$  -  $240\ \mu$  (Fig. 2), are similar in shape to the extra-uterine eggs (Drawings 6 and 9). The adult parasites live in the mesenteric and very occasionally in the vesical veins (about 3% of infected cattle in the Transvaal) of a wide variety of definitive hosts in nature, including baboons, monkeys, domestic stock, camels, rodents, equines, antelopes and occasionally man.

*S. bovis* (Sonsino, 1876) (Table 1; Fig. 1; Drawings 5 and 6)

This is a gut parasite first described from material obtained from cattle at the Zagazig abattoir in the Delta region of Egypt. It has a wide variety of natural definitive hosts, including cattle, sheep, goats, camels and pigs.

*S. bovis* has been reported from man from some Mediterranean and Middle East areas (Mahfouz, 1927; Soliman, 1956) but appears to be a very rare finding. Reported *S. bovis* infections from man from the rest of Africa and from elsewhere in the Middle East have never been confirmed by passage through laboratory animals and identification has been based on length and breadth measurements and general morphology. In some instances (Kisner et al., 1953), the eggs have been identified by Alves's (1949) formula and found to correspond to *S. bovis*.

The eggs measure about  $130\ \mu$  -  $260\ \mu$  in length (Fig. 1; Table 1). The processes of the eggs are narrow and it is often impossible to differentiate the spine from the posterior process. The eggs have no or little "shouldering" of the posterior process immediately anterior to the spine (Drawings 5 and 6).

The intermediate hosts are classically members of the *Bulinus truncatus* group but members of the *B. africanus* group have been incriminated in the Sudan (Malek, 1959), Kenya (Nelson et al., 1962), Somalia (Sobrero, 1960) and the Leopoldville Congo (Schwetz, 1951b).

*S. matthei* Veglia & Le Roux, 1929 (Table 1; Fig. 1; Drawings 7, 8 and 9)

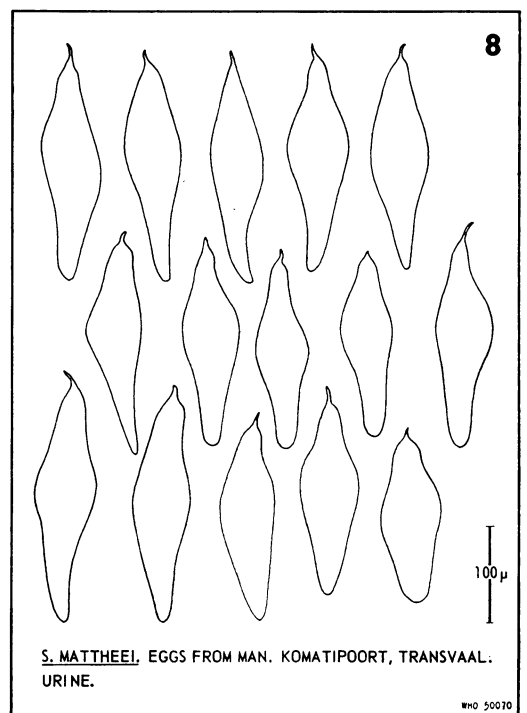
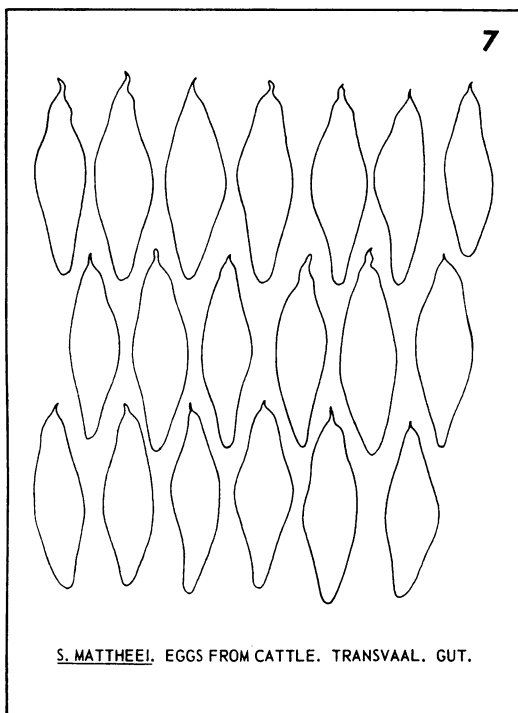
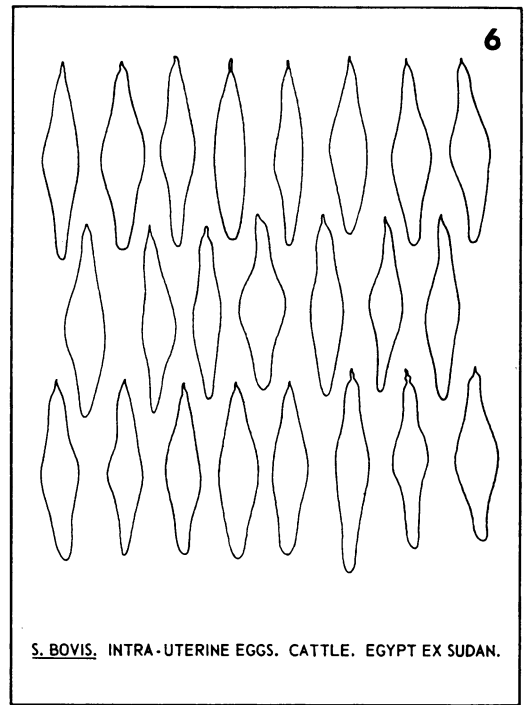
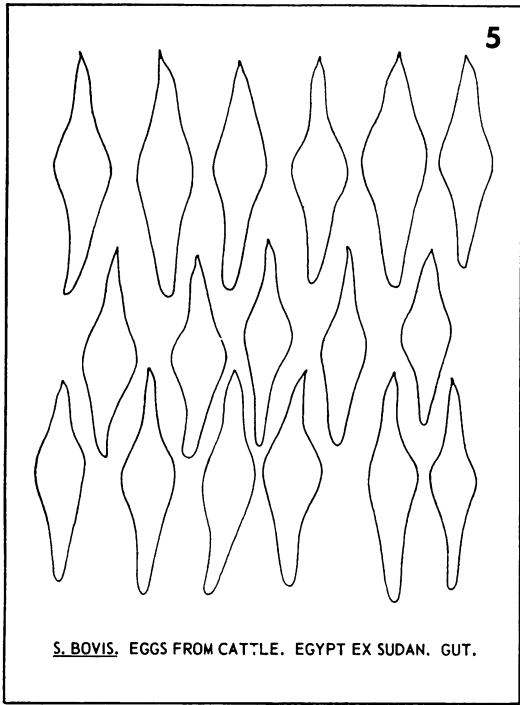
This parasite, with eggs similar to those of *S. bovis*, was originally described from the gut of sheep in the Cape Province of South Africa. It is now thought to occur as a gut parasite in southern Africa in a wide variety of definitive hosts including man. In man the eggs are found with equal frequency in the urine and the faeces (Pitchford, 1959b), but it cannot therefore be concluded that *S. matthei* is a bladder parasite in man as the females may have been carried there by *S. haematobium* males and so far *S. matthei* eggs originating from humans have not resulted in the production of typical or unmixed *S. matthei* eggs in the  $F_1$  or  $F_2$  generations respectively after passage through laboratory animals.

The spine of *S. matthei* eggs can usually be differentiated from the posterior process (Drawings 7, 8 and 9) but both intra- and extra-uterine eggs are indistinguishable from *S. bovis* eggs on length and breadth measurements alone (Table 1; Fig. 1 and 2). For this reason Alves (1949) separated these two parasites by measuring the length, maximum width and the width  $50\ \mu$  from the "blunt end" of the eggs and with two sets of formulae, to determine  $X_1$  and  $X_2$ , the axes of a graph,<sup>1</sup> was able to differentiate *S. bovis* from *S. matthei*. However, with these measurements and formulae, cattle schistosome eggs from man from the Transvaal were found to lie evenly distributed within the *S. matthei* and the *S. bovis* ranges (Fig. 3). There was, however, a marked difference observed between cattle schistosome eggs from northern and southern Africa with regard to the shouldering of the posterior process immediately anterior to the spine. In the northern

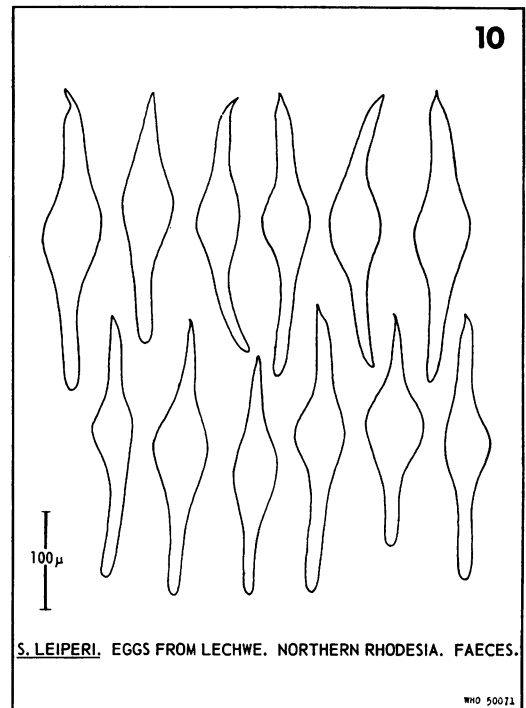
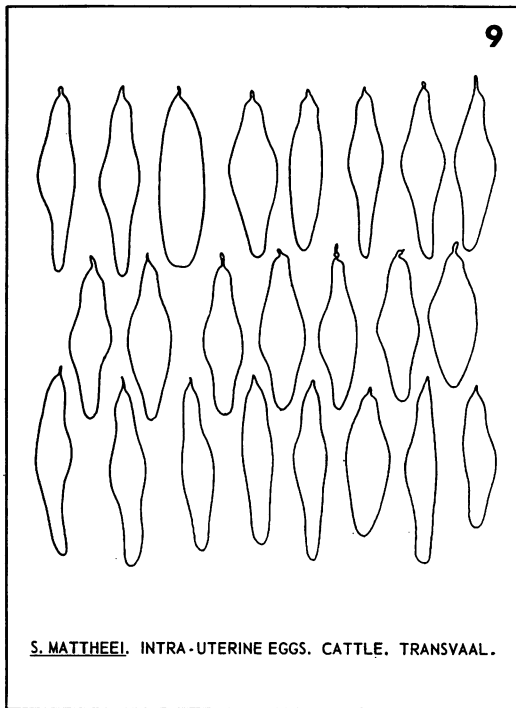
<sup>1</sup>  $X_1 = 0.46514x + 0.30226y - 1.8313z - 38.839$ , and  $X_2 = 1.08425x + 0.11858y - 1.427092z - 117.886$ , where  $x$  = length,  $y$  = maximum breadth and  $z$  = breadth  $50\ \mu$  from the "blunt end" of the egg.



DRAWINGS 5-8



## DRAWINGS 9 &amp; 10



(*S. bovis*) eggs the shoulder was lacking or very slight (Drawing 5) in comparison with the marked shoulder of the southern (*S. mattheei*) eggs (Drawings 7 and 8). Accordingly, presumed *S. bovis* eggs from Sudanese cattle, Iranian cattle and Iranian *Tatera indica*, the latter experimentally infected, and presumed *S. mattheei* eggs from naturally infected Transvaal sheep and Transvaal experimentally infected *Tatera leucogaster* were photographed and the width of the posterior process  $40\mu$  from the tip of the spine was measured. A distance of  $40\mu$  was chosen as it was greater than the length of the longest spine of *S. mattheei* measured in this laboratory and fell well within that portion of the egg where the shouldering would affect the shape. The results from 1915 of these egg measurements are shown in Table 2, and Fig. 4, where a well-marked difference between *S. mattheei* and *S. bovis* is seen; also, cattle schistosome eggs from man from the Transvaal were similar to *S. mattheei* eggs (Table 2). Other differences between *S. bovis* and *S. mattheei* parasites are that *S. mattheei* infects man quite commonly (Blackie, 1932; Pitchford, 1959b)

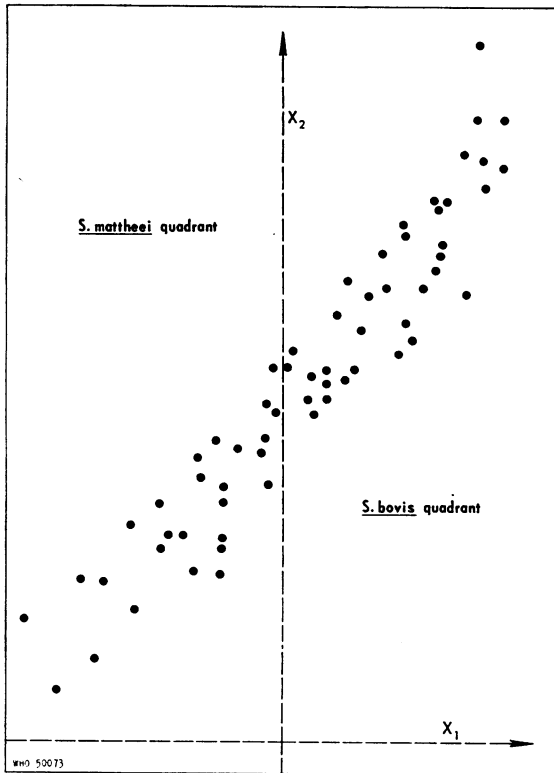
and will hybridize with *S. haematobium* from the southern half of Africa (Pitchford, 1961). This latter record has since been confirmed in the laboratory (unpublished data).

Previous reports indicated that the intermediate hosts of *S. mattheei* were members of the *Bulinus africanus* group only, but in this laboratory it has recently been found that a local Nelspruit snail of the *B. truncatus* group was also susceptible (see *S. capense* above). It therefore appears that the intermediate hosts of *S. mattheei* as well as of *S. bovis* must be considered as belonging to both the *africanus* and the *truncatus* groups. As with the previous group, therefore, there seems to be little evidence for separating the parasites on the basis of intermediate host susceptibility.

*S. curassoni* Brumpt, 1931 (Table 1)

This parasite was originally described on the basis of a very limited amount of material (two females) from the mesenteric veins of cattle in the then French Sudan. No mature eggs were studied and Brumpt (1931) himself admitted that the eggs were

FIG. 3  
DISTRIBUTION (APPLYING ALVES' FORMULA) OF  
*S. MATTHEEI* OVA FROM NATURAL INFECTIONS  
IN MAN IN THE TRANSVAAL



very like those of *S. mattheei*. Although no new material has been studied here the available evidence does not seem to offer any valid reason for separating this West African parasite from *S. mattheei*. They are both gut parasites with similar egg morphology and both have domestic stock as their definitive hosts. It is felt, therefore, that *Schistosoma curassoni* Brumpt, 1931, should be regarded as synonymous with *Schistosoma mattheei* Veglia & Le Roux, 1929, until more material has been studied.

*S. leiperi* Le Roux, 1955 (Table 1; Fig. 1; Drawing 10).

As yet very little work has been done on this gut parasite, which was described originally from material from situtunga (*Tragelephus spekei selousi*) from Northern Rhodesia; however, the abnormally long, thin, almost parallel-sided processes of the bipolar eggs, without differentiation between the spine and the posterior process and without shoul-

dering, appear to be sufficiently characteristic for it to be differentiated from any of the other species. In length the eggs measure about  $200\ \mu$ - $305\ \mu$ . Only a limited amount of material (150 eggs supplied by Dr P. L. Le Roux) from the faeces of red lechwe (an antelope) from Northern Rhodesia was available, and whether *S. leiperi* as observed here was merely a manifestation of *S. bovis* as seen in the lechwe is not known. The snail host is apparently *B. (Physopsis)* sp.; there is a very wide range of definitive hosts among antelopes and other animals and so far man is excluded. The distribution appears to be from Kenya to northern Bechuanaland.

#### THE INTERCALATUM GROUP

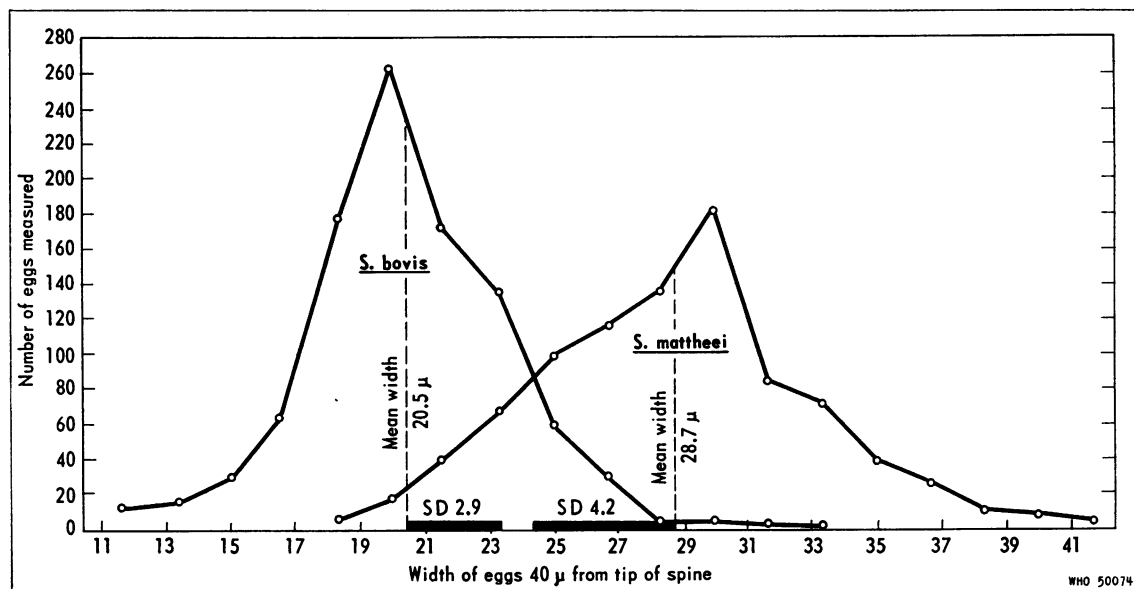
This group includes *S. intercalatum* Fisher, 1934, only. The eggs as Fisher found them are intermediate in morphology and measurement— $140\ \mu$ - $240\ \mu$  in length—between the *bovis* and *haematobium* groups. In nature the adult parasites live in the mesenteric veins of man and have been reported from sheep and goats infected artificially (Schwetz, 1956). So far as is known, the parasite has not been recovered from other naturally infected definitive hosts.

*S. intercalatum* Fisher, 1934 (Table 1)

This is a gut parasite of man first recorded by Chesterman in 1923 from the then Belgian Congo and subsequently described by Fisher (1934). It is believed that some patients have been also found with bladder infections.

The extra-uterine eggs are polymorphic, varying in shape from *S. haematobium* to *S. mattheei/bovis* (Fisher, 1934; Schwetz, 1951a). Intra-uterine eggs in material supplied by Dr P. L. Le Roux from laboratory-infected mice were indistinguishable from the intra-uterine eggs of a hybrid ( $F_2$  and  $F_4$ ) between *S. haematobium* and *S. mattheei* from the Transvaal (Fig. 2; Drawings 11 A, B, C). It has not been possible to examine any extra-uterine *S. intercalatum* material but there seems little doubt—judging from Fisher's illustrations and descriptions on extra- and intra-uterine eggs, Schwetz's (1951a) illustrations and descriptions of extra-uterine eggs, and personal observations on intra-uterine eggs—that the eggs would be indistinguishable from the hybrid (*S. haematobium/S. mattheei*) eggs from the Transvaal (Drawings 12 and 13). With intra-uterine eggs polymorphism, extending beyond the range of more than one schistosome group, was found within individual females and from female to female, in

FIG. 4  
WIDTH ( $\mu$ ) OF POSTERIOR PROCESSES OF *S. BOVIS* AND *S. MATTHEEI* EGGS 40  $\mu$  FROM TIP OF SPINE



both the hybrid and *S. intercalatum* (Drawings 11 A, B, C; Fig. 2) but was not a characteristic that was observed with the intra-uterine eggs of *S. haematobium*, *S. mattheei* or *S. bovis*. It was found only in alternate generations ( $F_2$  and  $F_4$ ) in the hybrid. It might be stated here that laboratory strains of *S. mattheei* and *S. haematobium* which have been kept in succeeding generations in rodents in Nelspruit since 1957 and 1960 respectively have shown no tendency to produce eggs which resemble the other species morphologically. However, on several occasions "wild" schistosomes, which are now all considered hybrids, produced eggs distinct from the original in either a pure form (Drawings 3 B, 12 and 14) or a mixed form (Drawings 13 and 11 A and 11 B). As several schistosome species with terminal-spined eggs and the same intermediate hosts are known to occur together in many places in Africa, hybridization of these species might be possible and account for many contradictory findings; it is felt that identification of schistosomes sometimes cannot be made with certainty unless they have been passaged through laboratory animals for at least two generations. If they then retain their original egg morphology they can probably be considered a pure species but if not, they should be considered hybrids or *S. intercalatum* depending

on the original definitive hosts, the site and locus from which they were collected and the known indigenous schistosomes. The behaviour of *S. intercalatum* in succeeding generations in laboratory animals is not yet known, but the eggs of a hybrid resulting from a natural infection in man with *S. mattheei* and *S. haematobium* in the Transvaal (Pitchford, 1961) eventually reverted to *S. mattheei* morphology after the  $F_5$  generation in rodents. This is thought to be possibly due to the definitive hosts in the laboratory being rodents and not man, and also to the fact that *S. haematobium* characteristics might have been eliminated through sacrificing the rodents too soon—i.e., between eight and 10 weeks, when *S. mattheei* reaches the stage of full egg production, instead of waiting for more than 13 weeks, when *S. haematobium* from the Transvaal reaches the stage of full egg production in rodents. The morphologies of the hybrid eggs are shown in Drawing 8, representing the original *S. mattheei* from man, Drawings 12 and 14, which represent both the  $F_1$  and  $F_3$  generations in laboratory animals, and Drawings 11B and 13, both of which represent the  $F_2$  and  $F_4$  generations in the laboratory rodents. Whether *S. intercalatum* is a distinct species or a hybrid resulting from a cross between *S. haematobium* and an animal schistosome, or

TABLE 2  
WIDTH OF *S. BOVIS* AND *S. MATTHEEI* EGGS AT 40 $\mu$  FROM SHARP END

Width ( $\mu$ ) at 40 $\mu$ from sharp end		<i>S. bovis</i>		<i>S. mattheei</i>	
<i>S. bovis</i> and <i>S. matthei</i> not from man	<i>S. matthei</i> from man	Iran	Sudan	Not from man; Transvaal	From man only; Transvaal
11.66		1	5		
13.33		1	6		
15.00		4	24		
16.66		15	48		
18.33		79	97	5	
20.00	19.98	151	110	18	4
21.66		129	43	38	
23.33	22.2	109	25	68	5
25.00	24.42	54	6	98	11
26.66	26.64	27	2	115	12
28.33		4		132	
30.00	28.86	5		176	14
31.66	31.08	2		82	17
33.33	33.3	1		73	5
35.00				35	
36.66	35.52			27	4
38.33	37.74			11	4
40.00				8	
41.66	42.18			4	1
Total		582	366	890	77
Mean		20.5		28.7	26.1
SD		2.9		4.2	4.7

whether *S. intercalatum* is more widespread than was originally supposed, is not known.

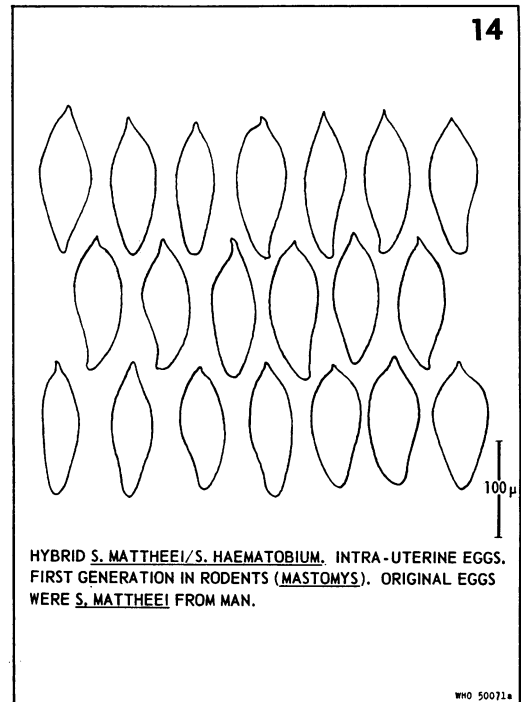
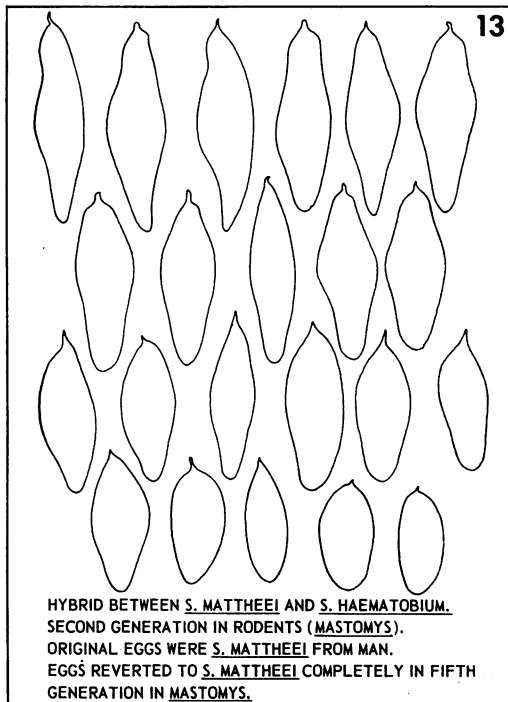
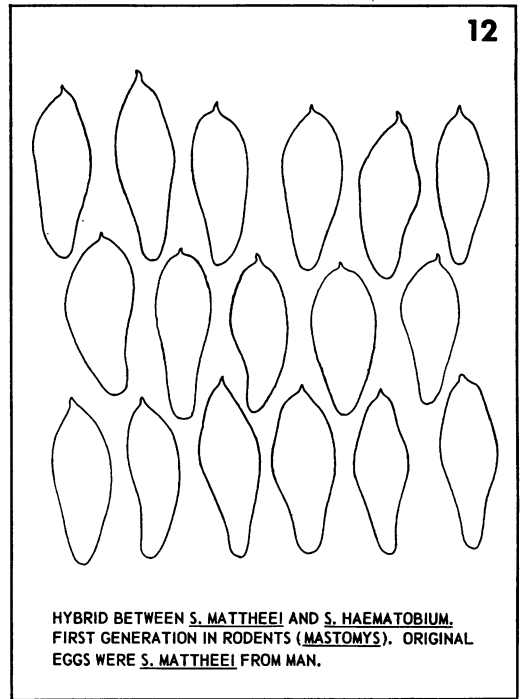
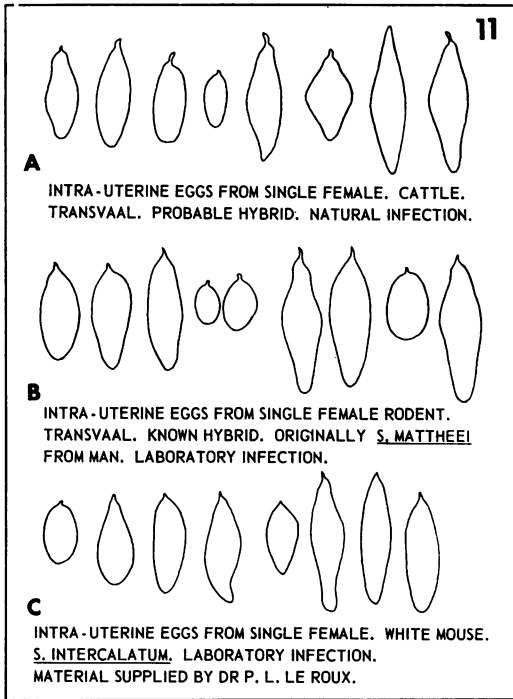
The gross polymorphism of *S. intercalatum* serves to differentiate it from parasites of the other groups; its known range of natural definitive hosts separates it from *S. mattheei* and *S. bovis*, its common site of election in man separates it from *S. haematobium* and *S. mattheei*; and its apparent preference for man as a definitive host would again tend to differentiate it from *S. mattheei*. It is felt, therefore, that it should be considered a separate species until investigated further along lines of egg morphology, other natural definitive hosts, time of development in both hosts and its behaviour in succeeding generations in laboratory animals.

The intermediate host has been reported so far as *Bulinus (Physopsis)* sp. only (Schwetz, 1956) but this hardly seems a distinguishing characteristic and there appears to be no valid reason as yet for separating any of these schistosomes on the basis of intermediate host susceptibility.

#### OTHER *SCHISTOSOMA* SPECIES REPORTED FROM AFRICA

*Schistosoma* species such as *S. spindale* and *S. indicum*, which have been reported from Africa, are not considered valid African species. In Africa, insufficient work has been done on them and the reports have never been confirmed in the laboratory.

DRAWINGS 11-14



## CONCLUSIONS

A great deal more study of these schistosomes is very necessary both in the laboratory and in the field throughout Africa and the Middle East. A few lines of investigation that may yield useful results are as follows.

(1) Developmental studies of the parasites in both the snail and the definitive hosts; for example, recent work has shown that the times of development of Transvaal *S. haematobium* and *S. mattheei*, both in the snail and in the definitive hosts, are very different (Pitchford & Visser<sup>1</sup>), whereas the rate of growth of *S. bovis* and *S. haematobium* in the definitive hosts is identical in mice in the Middle East (Lengy, 1962).

(2) Studies of the behaviour characteristics of certain species in succeeding generations in the laboratory, e.g., *S. intercalatum*.

(3) Studies of natural and experimental definitive host susceptibility.

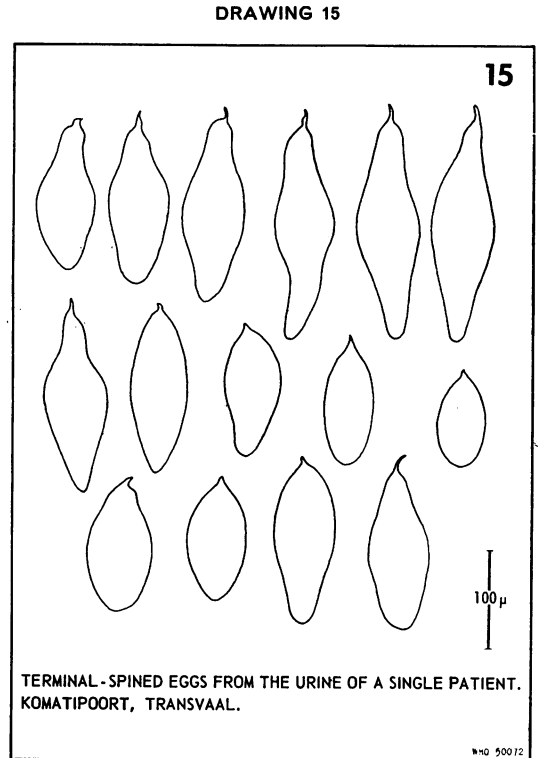
(4) Hybridization studies.

Finally, the following points must be stressed.

(1) Identification of schistosomes based on a few eggs only is highly dangerous. (Drawing 15 is typical of what is frequently found and well illustrates the difficulty of identification based on few eggs.) This has been pointed out repeatedly on numerous occasions by numerous authors but little attention seems to have been paid to it.

(2) Passage of schistosomes through laboratory animals is sometimes essential in order to be able to make an identification. With schistosomes studied in this laboratory it has not been found that egg morphology differs grossly with different definitive hosts under routine conditions.

(3) Egg measurements of length and breadth are not considered of much value in themselves, especially in the *bovis* group; of more use is the general



shape of a large number of eggs in conjunction with measurements. Isolated eggs in a group, which are obviously abnormal in morphology, should be disregarded unless found repeatedly in different loci, or unless they are passaged through laboratory animals and subsequently recovered in the original shape. The most posterior egg in the uterus is often apparently abnormal and should also be disregarded when attempting to identify the adult female.

(4) Identification based on dead, calcified, immature, swollen or squashed eggs is usually impossible and should not be attempted except in differentiating the terminal- from the lateral-spined eggs.

<sup>1</sup> See the article on page 83 of this issue.

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rial; to the WHO Bilharziasis Unit, Desful, Iran, and to Dr M. A. E. Ezzat for their assistance in collecting *S. bovis* material in Iran and Egypt.

## RÉSUMÉ

L'identification et la différenciation des schistosomes dont les œufs possèdent un éperon terminal ne sont pas toujours aisées. Certains des critères généralement utilisés, et notamment la recherche des possibilités d'infection d'hôtes intermédiaires, ne représentent pas des moyens sûrs de détermination.

Bien que l'étude de la morphologie des œufs n'offre pas une garantie absolue, c'est sur cette base, et en tenant compte d'autres particularités, comme les modalités de la ponte et l'hôte définitif naturel, que l'auteur propose une classification de certains schistosomes d'Afrique et du Moyen-Orient en trois grands groupes: le groupe *haematobium*, qui ne renferme qu'une seule espèce, *S. haematobium*; le groupe *bovis* formé des espèces *S. bovis*, *S. matthei* et *S. leiperi*; et le groupe *intercalatum* lui aussi représenté par une seule espèce, *S. intercalatum*. Il semble qu'une subdivision plus poussée du genre *Schistosoma* ne se justifie pas actuellement, et que *S. capense* et *S. curassoni* décrits précédemment doivent être considérés comme identiques à *S. haematobium* et *S. matthei* respectivement. Une particularité morphologique non encore signalée permet de différencier les œufs de *S. bovis* et *S. matthei*. Quant au polymorphisme des œufs intra- ou extra-utérins, il semble se maintenir dans les limites des caractéristiques de l'espèce, sauf s'il s'agit d'hybrides ou de *S. intercalatum*.

*bium*; le groupe *bovis* formé des espèces *S. bovis*, *S. matthei* et *S. leiperi*; et le groupe *intercalatum* lui aussi représenté par une seule espèce, *S. intercalatum*. Il semble qu'une subdivision plus poussée du genre *Schistosoma* ne se justifie pas actuellement, et que *S. capense* et *S. curassoni* décrits précédemment doivent être considérés comme identiques à *S. haematobium* et *S. matthei* respectivement. Une particularité morphologique non encore signalée permet de différencier les œufs de *S. bovis* et *S. matthei*. Quant au polymorphisme des œufs intra- ou extra-utérins, il semble se maintenir dans les limites des caractéristiques de l'espèce, sauf s'il s'agit d'hybrides ou de *S. intercalatum*.

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