Mahesh Chandra Agrawal

Schistosomes and Schistosomiasis in South Asia

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Acknowledgement

During our service period, hardly do we get time to write any reference book, particularly if we are involved in administration and have an eye on fulfilling targets of our research projects or completion of students' theses. When we retire, there is plenty of time to devote to our creativities, but having lost the incentive of moulding our career, lethargy engulfs us. At this moment, it is only larger incentive and commitment that motivate our work. And this was precisely the commitment which empowered me to complete this task of writing the reference book *Schistosomes and Schistosomiasis in South Asia*.

I commenced writing this book in the house of my second daughter Ritu and her husband Mudit Shah in Bangalore on 7 April 2008 (*Guri Parva*) with the Vedic hymn '*Tamso maa jyotirgamay*' (O Mother! Lead me from darkness to light) on a sheet of paper, but my techno-savvy Ritu and Mudit advised me to waive 'pen and paper' approach and to write directly on computer and helped me to learn all the finer details of this new method. Their suggestion and guidance helped me to conclude the book as a computer file. Now I realize how arduous it would have been to follow pen-paper method, especially when our publisher Springer India Private Limited also banks on computers, thereby completely casting aside paper work.

My eldest son-in-law Wing Commander Prashant Gupta and his wife Namita Gupta came to my rescue for converting all the photographs, which have appeared in the book, in a digital form and arranging them with specific captions. Prashant also helped me in searching and sorting research work and arranging references against each chapter—really a difficult task. My youngest daughter Shipra Agrawal and her husband Utsav Agrawal assisted me during editing of the chapters. It was my wife Mrs. Veena Agrawal who always took care of me with loads of love and devotion and made it possible for me to concentrate on the book. My lovely grand children Kush, Ruhan and Tanav engaged me with their jolly, naughty acts and sweet talks which worked as a perfect tonic for me. I am indebted to all my family members who helped me in one or the other way in writing this book.

I intended to incorporate all the important research work carried out in India and neighbouring countries on the schistosome species since when it was discovered in South Asia so that the book may become a significant document for future reference.

As the writing of this book was in my mind since long, I continued to gather as many references as possible. My seniors, colleagues, students and scientists abroad greatly helped me in this endeavour by forwarding research papers/chapters/reviews to me. I am thankful to all of them. I am particularly thankful to Drs. J. Jourdane, France; V. R. Southgate, UK; G. J. Vandam, the Netherlands; late Dr. K. E. Mott, WHO; late Dr. V. S. Alwar, Chennai; late Dr. B. S. Chauhan, Sagar; and Drs. N. Chowdhary, Ludhiana, V. P. Sharma, New Delhi, V. G. Rao, Jabalpur, and P. D'Souza, Bangalore, for their encouragement and supplying research material; thanks to my students Drs. P. S. Banerjee, IVRI; S. Vohara, HAU; Samidha Gupta, Raipur; B. K. Singh, Hyderabad; C. Upadhyaya, Jabalpur; and S. Kohli, Mumbai, for rendering me their research papers and also their theses work and photographs, which have been used extensively in this book. I am thankful to the different libraries of the country which provided me continuous access to the periodicals and other materials.

I have incorporated photographs which, in my opinion, will be of help to future research workers. I am thankful to Maney Publishing House, UK, for permitting to reproduce the photograph of egg of *Orientobilharzia harinasutai* (Fig. 2.6) which needs further investigations in South Asia. Likewise, there are other important photographs, some of which are taken from our research papers from different journals while others from theses and research schemes. I am thankful to the management and editors, *Journal of Veterinary Parasitology* (*IAAVP*), *Indian Journal of Parasitology* (*ISP or JPD*) and *Indian Journal of Animal Sciences* (*ICAR*), for permitting me to reproduce photographs.

I wanted the book to be offered for sale not only in India but other countries also as I believe it is necessary that our international scientific community should be conscious about the work on Indian schistosomes so that a new line of research, including comparative studies, should be followed to resolve the global problem of schistosomiasis. As Springer has presence in many countries, it is my pleasure that they agreed to publish this book; I am thankful to them and their staff Drs. Priti Nanda, Mamta Kapila, Richa Sharma and Meena Chandramohanan for their tireless efforts in improving the quality of this book.

Last but not the least, I am indebted to my professor late Dr. S. C. Dutt who taught me the basics of schistosomes and schistosomiasis without which writing of this book would not have been possible.

Jabalpur Mahesh Chandra Agrawal

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Chapter 1
Introduction

Schistosomiasis or schistosomosis or bilharziasis is the disease or rather a disease complex caused by different species of schistosomes or blood flukes. This disease complex affects both human beings and animals, including wild animals, and is prevalent throughout the globe in one form or other. Though the USA and European countries are considered free from this disease, the species of *Heterobilharzia* or avian schistosomes prevalent there affect the health of humans in the form of cercarial dermatitis. The disease is widely prevalent among waterborne diseases and is considered next only to malaria, affecting more than 74 countries and 200 million people with 600 million people being exposed to the infection. The latter affects only human beings, while the former affects animals as well.

Schistosomiasis has become so complex that it is not possible for one health specialist to deal with it but requires experts from many other specialties, namely, clinician, veterinarian, epidemiologist, immunologist, pathologist, parasitologist, diagnostician, and pharmacologist.

The studies for understanding taxonomy, snail hosts, and biological variations including genetic variations are done by zoologist, helminthologist, taxonomist, malacologist, geneticist, and molecular biologists. To study the evolution of schistosomes and their spread, deep knowledge on geography, hydrobiology, climatology, and evolutionary biology is required. To complicate the matter, there are as many as 22 *Schistosoma* species, spread throughout the globe, which are different in their biology and ability of causing disease in humans and animals, thereby warranting specific knowledge of the particular *Schistosoma* species.

Not only more experts but also sophisticated equipments are required, which are in short supply in Asian and African countries where the disease is widely prevalent. There is also paucity of funds. As the disease is mainly prevalent in African and Asian countries, it was neglected by the international scientific community, although these developing countries were suffering from loss of man power, working days, mortality, and loss of animal production. There were some politico-geological changes in early 1970s when World Health Organization (WHO) along with UNDP (United Nations Development Program) and World Bank decided to contain six important diseases affecting almost two-thirds of the

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human population. Schistosomiasis was one of them, the others being malaria, filariasis (including onchocerciasis), trypanosomiases (sleeping sickness and Chagas' disease), leishmaniases, and leprosy. These diseases were brought under a special program for research and training in tropical diseases (TDR). WHO funded various schemes in different countries to work on the development of effective drugs, diagnosis, and control of schistosomiasis excluding India, perhaps, on the pretext that there was no recent report of human schistosomiasis from the country, although India possesses the largest number of mammalian schistosome species whose details are still unknown. Efforts by WHO and other scientific bodies resulted in the development of effective schistosomicides like praziquantel, niridazole, and oxamniquine and effective parasitological diagnostic methods like Kato-katz technique for fecal examination and Nuclepore filtration technique for urine examination.

India has a history of schistosomiasis of over 100 years and is keeping pace with its global development. After the discovery of *Distoma haematobium* (earlier name of *Schistosoma haematobium*) in a person in Cairo, Egypt, in 1851 (described in 1852), India reported its first case of human urinary schistosomiasis in an Englishman in 1878 followed by reports of schistosomes in cattle from Calcutta by Dr. TS Cobbold (1882) and Dr. G Bomford (1886). Subsequently, there were sporadic reports of human infections, but work in this direction showed little possibility of spread of human schistosomiasis in the country as desired snail species could not be identified. This resulted in loss of interest in the disease in India. This claim of nonendemicity did not sustain for long as cases of urinary schistosomiasis were reported from Gimvi village of Ratnagiri district, Maharashtra, in 1952 and infrequent reports of schistosome eggs in human excreta. In preindependent India, the scientific work, carried out by Drs. RE Montgomery, F Milton, MB Soparkar, WG Liston, FH Gravely, NH Fairley, RBS Sewell, SW Kemp, AC Chandler, and others, was strengthened by emerging generation of Indian scientists, namely, Drs. MAN Rao, PG Malkani, SCA Datta, GD Bhalerao, OK Khaw, SV Mudaliar, HR Mehra, RS Ayyar, MA Moghe, HD Srivastava, BS Chauhan, and others. Research centers were developed by these scientists who carried out remarkable work on schistosomiasis. Some of the important research centers in India where advanced research on mammalian schistosomes and schistosomiasis was carried out are as follows:

Madras (Chennai): After Calcutta (Kolkatta), where Chandler discovered *S. incognitum*, Madras Veterinary College emerged as an important research center where *Schistosoma nasalis*, *S. suis* (*syn. S. incognitum*), and *Bivitellobilharzia nairi* were discovered. Detailed studies were carried out on these and other blood flukes by Drs. MAN Rao, RSP Ayyar, CT Peter, and SV Mudaliar. An All India Coordinated Research Project on "Investigations into the factors governing the epizootiology of nasal schistosomiasis in bovines and its control in different field conditions," sanctioned by ICAR (Indian Council of Agricultural Research) in 1971 for 3 years was implemented at Madras Veterinary College under Dr. VS Alwar as project coordinator. Nagpur, Bangalore, and Bhubaneswar were the other centers. This further strengthened the Madras center, resulting in a number of M.V.Sc. and Ph.D. theses on schistosomiasis.

Izatnagar: It was from Mukteswar, the main seat of IVRI (Indian Veterinary Research Institute), that Dr. RE Montgomery described three new schistosome species in 1906. Later, IVRI, Izatnagar, emerged as an important research center where Drs. HD Srivastava, SC Dutt, and their associates worked on almost all species of schistosomes, prevalent in India. They investigated the life cycle, described the morphology, and even created new genus and species of schistosomes. A detailed study was done on *S. indicum* which culminated in the publication of a monograph in 1962. A number of Indian scientists worked for their Ph.D. on schistosomiasis at IVRI. With the retirement of Dr. HD Srivastava and shifting of Dr. SC Dutt to Jabalpur, IVRI lost its experienced schistosomologists which resulted in loss of interest in schistosomiasis in this premier research institute.

Jabalpur: After Dr. SC Dutt joined JNKVV (Jawaharlal Nehru Krishi Vishwa Vidyalaya) in 1969 as professor and head of parasitology, College of Veterinary Science and Animal Husbandry, Jabalpur, he initiated experimental work on schistosomiasis. This work was further advanced with the sanction of an ad hoc ICAR research scheme on "Investigation into the immunology of schistosome infection with a view to evolving a vaccine." A number of students worked for their MVSc and Ph.D. on schistosomiasis. Research was carried on different aspects of immunity using mice, rats, rabbits, and in one case piglets also. Even after Dr. Dutt left Jabalpur in 1974, the work on schistosomiasis was continued by Dr. MC Agrawal, his student and the author of this book. Sanction of a National Fellow scheme by the ICAR, New Delhi, in 1995 to this author which was the first of its kind both in JNKVV and in the field of parasitology in India opened new vistas on research on schistosomiasis. Jabalpur was also made a center of the NATP project on "Diagnosis of parasitic diseases in domestic animals," enabling purchase of good equipments, thus opening the doors for molecular studies and immunodiagnosis on schistosomiasis. An emeritus scientist scheme was also sanctioned by ICAR to control schistosomiasis under field conditions. These facilities helped to work on different aspects of schistosomiasis and developing simple techniques for the maintenance of the snails in the laboratory, infecting large animals, perfusion technique for fluke recovery, and immunodiagnosis.

Bangalore: Being a center of All India Coordinated Project on nasal schistosomiasis, work was carried out at Veterinary College by Drs. K Muraleedharan, A Rahman, and others on understanding its epidemiology and experimenting on molluscicides and other drugs. The center also undertook work on immunodiagnosis and survey of hepato-intestinal schistosomiasis in Karnataka.

Nagpur: Dr. MA Moghe initiated work on schistosomiasis at Nagpur, which was also a center of All India Coordinated Project on nasal schistosomiasis (under Department of Animal Husbandry). Dr. NG Bhilegaonkar, who obtained his Ph.D. on schistosomiasis from Jabalpur, continued to work on schistosomiasis and guided several M.V.Sc. students at the Nagpur Veterinary College.

Apart from the above centers where schistosome work continued for more than 10 years, other research institutes which contributed toward the advancement of knowledge on schistosomiasis are Veterinary Colleges at Bhubaneswar, Patna, Mathura, Guwahati, and Hisar; Medical college/Haffkine Institute, Bombay; regional medical research centers (ICMR) at Dibrugarh and Jabalpur: universities of Allahabad and Lukcnow.

These works were mainly supported by the following national organizations:

Indian Army: The role of the medical core of the Indian Army in investigations on schistosomiasis, during the First and Second World Wars, cannot be ignored. It was the army which was interested in combating the disease which infected their troops who were either stationed in India or those who visited endemic countries during the war. In fact, it was on the request of the army that scientists undertook investigations on schistosomiasis in India.

Indian Council of Medical Research (ICMR): After reports of presence of *S. haematobium* and *S. japonicum*, in preindependent India, the erstwhile Empirical Council of Medical Research requested scientists, including scientists of Zoological Survey of India, to ascertain chances of disease establishment in India. ICMR again played an active role when Drs. RK Gadgil and SN Shah reported cases of urinary schistosomiasis from Gimvi village of Ratnagiri district but showed less interest when no other confirmed foci were reported from other parts of the country.

Zoological Survey of India (ZSI): The ZSI played a big role in declaring India free from human schistosomiasis as its scientists failed to discover any snail host responsible for the spread of human schistosomiasis and also noninfectivity of local snails with miracidia of *S. haematobium*. However, the advice of Drs. BS Chauhan and Ramakrishna of ZSI to restudy the life cycle of *S. haematobium* in India was not carried out.

Indian Council of Agricultural Research (ICAR): As evidence accumulated on losses in animal industry due to schistosomiasis, particularly the nasal form, the ICAR, New Delhi—the main research organization in the country responsible for research on livestock health—sanctioned an All India Coordinated Project on nasal schistosomiasis between 1971 and 1974 with Dr. VS Alwar of Madras Veterinary College as project coordinator. An ICAR National Fellowship on schistosomiasis was given to Dr. MC Agrawal from Jabalpur. Two research centers on schistosomiasis at Jabalpur and Hisar under NATP were sanctioned, besides few ad hoc research projects on schistosomiasis.

However, none of these research organizations could recognize the complexities of schistosomes and schistosomiasis and hence failed to establish a well-developed research center in India on the subject. Though many endemic countries included control of schistosomiasis under the government policy which boosted scientific work on schistosomes and schistosomiasis, this was not done in India, perhaps because of infrequent reporting of human schistosomiasis in the country. This resulted in confinement of research by individuals under restricted research facilities. Ironically, even international organizations, which have international research centers on schistosomiasis in some European countries, where infection is nonexistent, also ignored this geography and schistosomes, specific to these places. Even the work from India and other South Asian countries has remained mostly isolated from international collaboration, thereby losing an important opportunity of carrying out comparable studies for better understanding of schistosomes and schistosomiasis.

Thus, it is clear that most of the work on schistosomiasis was carried out in South Asia on individual basis with limitations which resulted in lack of proper data generation. This was realized during compilation of data on schistosomiasis from different sources (hospitals, diagnostic laboratories, veterinary/medical departments, state, and central governments) for this book. This compilation from different sources is important as peer-reviewed research journals publish only important observations. Thus, scientific literature fails to provide a detailed view of the infection in the whole of South Asia. These journals have not reported each and every outbreak, nor its prevalence in domestic animals, or spread of cercarial dermatitis in humans. Hence, depending on these research journals will restrict our knowledge on spread of the infection. No doubt, review of postgraduate theses, technical reports of research schemes, lectures, etc., provided additional information, but it is prudent to gather field data on schistosomiasis. We, therefore, visited veterinary hospitals—both at village and district levels—and veterinary diagnostic laboratories of state governments to retrieve information on schistosomiasis or diarrhea-related conditions. But it was noticed that these hospitals maintain a single register for all species of animals where the ailments and line of treatment are recorded daily. Follow-up of these cases from the register was impossible. Though it is beyond doubt that our village hospitals are important sources for collecting disease-related data, it will be possible only after changing the pattern of recording data in our health centers.

Additionally, we tried to obtain schistosomiasis-related information from animal husbandry departments and national research centers on camel, equine, and RVC (Remount Veterinary Corps). We were informed that there are only certain diseases whose records are maintained, and schistosomiasis does not fall under this schedule. Obviously, there is a need for a relook at our priorities and incorporate diseases which influence the animal population, especially the domestic ones, and also a threat to human health. Hopefully, this book will incite interest to pay more attention to schistosomiasis and such other infections that are affecting both human beings and animals.

Despite all these limitations, work has been done in South Asia on schistosomes and schistosomiasis which needs attention of the international scientific community. Though there are some important review articles and a few chapters on Indian schistosomes, there is no comprehensive book dealing exclusively on Indian schistosomes and schistosomiasis. Therefore, we have attempted to analyze the available literature for writing this book which will rekindle the interest of the scientific community. In our opinion, the subject will be of interest to biologists to get answers to topics/questions on how the schistosome evades coagulative mechanism despite being a foreign body in the blood vascular system; why dead schistosomes do not cause thrombosis; how the female mates other schistosome species for its development and even for hybrid formation but generally shifts to homogenous males whenever they are available; hybrid is formed in heterologous mating; how it shifts to lung or liver for escaping drug effect and mechanism for heterologous stimulation; or how *Bivitellobilharzia* has been existing since millions of years (?) only in one host species—the elephant—without the fear of extinction. What are the reasons for low egg production by Indian schistosomes, escaping of human beings despite prevalence of large number of mammalian schistosomes, why the Indian schistosome does not utilize the river system, and why effective drugs like praziquantel or oxamniquine fail to reduce Indian schistosome population in any host system to a significant level? Moreover, nasal schistosomiasis is the only model in different types of schistosomiasis where nasal lesions may be monitored grossly, without necropsy, and hence may be employed advantageously in field drug trials and vaccination programs.

Despite continued research, there is no respite from nasal schistosomiasis in cattle, or outbreaks of hepatic schistosomiasis leading to considerable mortality in cattle and sheep, or continued animal production losses in the form of low body weight and low milk yield. A large segment of rural population is having cercarial dermatitis but without knowledge that how many of them are suffering from active schistosomiasis—where live schistosomes exist in lung, liver, or mesentery. Cases of urinary or hepatic schistosomiasis in rural areas are not diagnosed due to the socioeconomic conditions and difficulty in diagnosis due to nonavailability of modern diagnostic tests.

A complacent view on schistosomiasis, in South Asia, cannot be taken as it may lead to more complications, particularly as efforts are being made to harvest rainwater in the villages. Continued research on schistosomes and schistosomiasis is needed to develop vaccines, new drugs or combination of drugs, and new methods of diagnosis including detection of schistosome antigen in the excreta under different field conditions. A scientific strategy incorporating controlling agents like dragonfly nymphets which survive in identical habitats for a year or more and animal management depending on egg and cercarial shedding may minimize the intensity and morbidity of the infection. We are hopeful that this book will motivate new research on schistosomes and schistosomiasis in South Asia which will eventually help in controlling the infection in these countries.

Chapter 2
The Schistosomes

The schistosomes or blood flukes or *Bilharzia* belong to phylum Platyhelminthes, class Trematoda, and subclass Digenea. They are flat, inhabit blood vascular system of the host, and require a snail host to complete its life cycle. As schistosomes are responsible for a major human disease, extensive work has been carried out on these parasites. This work includes taxonomic discussions, understanding the biology of the flukes and also the evolution of the schistosomes.

2.1 Taxonomic Considerations

Several documents have dealt with the taxonomy of schistosomes with special reference to Indian schistosomes. Among them, some, are the following: the monograph titled "Helminth Parasites of the Domesticated Animals" by GD Bhalerao, published by Imperial Council of Agriculture Research in 1935; important research papers by Srivastava and Dutt, creating a new genus and species of schistosomes; the Presidential address by Srivastava (1960) on "Blood flukes" in the Indian Science Congress, Bombay; the review of Chauhan et al. (1973) "Studies on the trematode fauna of India: Part 6. Digenea: schistosomatidae"; and a comprehensive chapter on "The genus *Schistosoma*: a taxonomic appraisal" by Rollinson and Southgate (1987), covering Indian schistosomes as well. Our present discussion will evaluate these observations and highlight the limitations in identifying even adult blood flukes at the species level.

One of the earliest work is the monograph by Bhalerao (1935) which describes the schistosomes existing in India under family Schistosomidae (Loss 1899) (or Schistosomatidae (Loss 1899)), showing only two genus—*Ornithobilharzia* (Odhner 1912) and *Schistosoma* (Weinland 1858). The main characteristics of *Ornithobilharzia* are 60 or more testes and spiral ovary in anterior third, whereas *Schistosoma* has 3–12 testes and equatorial or postequatorial ovary. In the first genus, the type of species is *O. intermedia* (Odhner 1912) and other is *O. bomfordi,* described by Montgomery in 1906 from India as *Schistosoma bomfordi*.

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In the genus *Schistosoma*, Bhalerao has described four species—*S. haematobium*, *S. indicum*, *S. spindale*, and *S. bovis*—which according to him were then prevalent in India, and interestingly, there is no mention either of *S. incognitum* or *S. nasalis* which were discovered in 1926 and 1933, respectively.

In schistosomes, sexes are separate, and body is elongate with formation of a gynecophoric canal, on the ventral site in males, by folding the lateral part of the body where the female is carried by the male. We are reproducing the key to the species of *Schistosoma*, provided by Bhalerao, only to suggest how insufficient the data was on which species have been diagnosed:

1.	Eggs oval…………………………………………………	2
	Eggs spindle-shaped………………………………………	3
2.	Intestinal ceca of male unite near equator of body………..	*S. haematobium*
	Intestinal ceca of male unite posterior to equator of body…	*S. indicum*
3.	Eggs asymmetrical, measuring 0.248–0.400 × 0.052–0.072	*S. spindale*
	Eggs symmetrical, measuring 0.16–0.18 × 0.045–0.08……	*S. bovis*

It is of little wonder then that many workers have reported the existence of *S. haematobium* and *S. japonicum* (Bhalerao 1934, 1948; Moghe 1945) from India, whose existence was later disputed. If the above key is followed, it is difficult to identify either *S. nasale* or *S. incognitum*. Simultaneously, it also reflects problems in differentiating schistosome species with conformity on morphological grounds alone.

In fact, Stiles and Hassall created a superfamily Schistosomatoidea in 1926 where three families, namely, Schistosomatidae (Loss 1899), Sanguinicolidae (Graff 1907), and Spirorchiidae (Stunkard 1921), were placed together with the main characteristic that all these flukes inhabit the blood vascular system of their host. The members of the first family inhabit mammals and birds, whereas fish and turtle are hosts for remaining two families.

As members of Schistosomatidae parasitize mammals (including man) and birds, this family has attracted a lot of attention and consists of four subfamilies, i.e., Schistosomatinae (Stiles and Hassall 1898), Bilharziellinae (Price 1929), Dendritobilharziinae (Mehra 1940), and Gigantobilharziinae (Mehra 1940). Members of the subfamily Schistosomatinae occur both in birds and mammals, while those of the other three subfamilies occur exclusively in birds. In subfamily Gigantobilharziinae, ventral sucker is always absent, and genital pore in the females is medially near the anterior end of the body. On the other hand, both suckers are present in Bilharziellinae where genital opening in female is posterior to ventral sucker. There is no mention of subfamily Dendritobilharziinae by Rollinson and Southgate (1987) who maintained that the family Schistosomatidae contains only three subfamilies. However, in subfamily Dendritobilharziinae, there is only one genus, *Dendritobilharzia* (Skrjabin and Zakharow 1920), with *D. pulverulenta* (Braun 1901) (Skrjabin 1924) as its type species; the only Indian species of the genus, described by Mehra (1940), is *D. asiaticus*. Members of this subfamily are characterized by absence of both suckers and common cecum equipped with lateral dendritically branching diverticulae.

2.1.1 Subfamily Schistosomatinae

The diagnosis of subfamily Schistosomatinae is as follows:

> Both suckers present, males with gynaecophoric canal, testes always anterior to cecal union, intestinal ceca long, usually uniting posterior to equatorial line of body, common cecum relatively short. Female slender, threadlike, either longer or shorter than male, genital pore postacetabular, ovary preequatorial, uterus usually with many eggs. Type genus is *Schistosoma* (Weinland 1858).

Schistosomatinae contains ten genera: *Schistosoma* (Weinland 1858), *Ornithobilharzia* (Odhner 1912)—modified by Dutt and Srivastava (1955, 1961a) by creating two more genera, *Orientobilharzia* and *Sinobilharzia* (Dutt and Srivastava 1955)—*Austrobilharzia* (Johnston 1917), *Macrobilharzia* (Travassos 1923), *Schistosomatium* (Tanabe 1923), *Heterobilharzia* (Price 1929), *Microbilharzia* (Price 1929), and *Bivitellobilharzia* (Vogel and Minning 1940). The chief characteristics of these ten genera are given in Table 2.1 (several scientists do not consider *Sinobilharzia* and *Microbilharzia* as valid genera), while key of four genera of subfamily Schistosomatinae, prevalent in India and discussed by Chauhan et al. (1973), is given below:

1	Gynaecophoric canal well developed; testes 48–85 in number; vitellaria in two sets; parasitic in mammals……	*Bivitellobilharzia*
	Gynaecophoric canal well developed; only one set of vitellaria; parasitic in mammals or birds………………	2
	Ovary just cephalad to cecal union, oval or cylindrical; testes 37–80 in number; cirrus pouch absent……………	*Orientobilharzia*
	Ovary just cephalad to cecal union, oval or cylindrical; testes fewer, not more than 16; cirrus pouch absent……	*Schistosoma*
	Female unknown; acetabulum pedunculate with scalloped or festooned margin; testes numerous (180–200); cirrus sac present……………………………	*Baughbilharzia* (new genus)

Bivitellobilharzia was considered to exclusively parasitize mammals, but according to Chauhan et al. (1973), all the three last genera parasitize mammals or birds. But subsequent work has conclusively found occurrence of *Schistosoma* and *Orientobilharzia* only in mammals; The new genus *Baughbilharzia* was created by Chauhan et al. (1973) for the blood fluke *Ornithobilharzia phalacrocoraxi* that was recovered by Baugh (1963) from portal vessel of the bird *Phalacrocorax niger* from Hardoi, U.P., due to some dissimilarities from genus *Ornithobilharzia*; this nomenclature has not been accepted by the international scientific community.

2.1.1.1 Genus *Schistosoma*

Genus *Schistosoma* is most important as it includes species that are important for human and animal health. Though the first blood fluke discovered was an avian parasite *Ornithobilharzia canaliculata* (Rudolphi 1819;Odhner 1912), it was the

Table 2.1 Main differentiating features of different genera under subfamily Schistosomatinae (After Dutt and Srivastava 1961a)

Genus	No. of testes	Position of testes	Shape of ovary	Greatest width/length of ovary	Spiral nature of ovary	Position of ovary
Schistosoma	3–16	Little behind acetabulum	Oval to cylindrical	1/2–1/8	Anterior slender portion, if present, loosely spiral	Anterior third to posterior half, just cephalad of cecal union
Orientobilharzia	37–80	Little behind acetabulum	Oval to cylindrical	1/3–1/5	Anterior slender portion, if present, loosely or tightly spiral	Anterior third or middle third, just cephalad of cecal union
Bivitellobilharzia	48–85	Little behind acetabulum	Cylindrical	1/5–1/6	Loosely spiral	Anterior third, far cephalad of cecal union
Ornithobilharzia	25–120	Little behind acetabulum	Tubular and elongated	1/20–1/65	Very loosely spiral	Anterior third, just cephalad of cecal union
Sinobilharzia[a]	65	Much behind acetabulum	Tubular	1/8	All throughout loosely spiral	Anterior third, far cephalad of cecal union
Macrobilharzia	230–250	A little behind acetabulum	Cylindrical	1/4	All throughout loosely spiral	Posterior third, far cephalad of cecal union
Microbilharzia[a]	18–26	A little behind acetabulum	Cylindrical	1/4	All throughout loosely spiral	Preequatorial
Austrobilharzia	12–26	A little behind acetabulum	Cylindrical	1/7	Loosely spiral	Equatorial, just cephalad of cecal union
Heterobilharzia	60–80	Far behind acetabulum, in posterior third of body	Tubular forming four loops	1/4	Forming 4 loops	Preequatorial, far cephalad of cecal union
Schistosomatium	15–36	Far behind acetabulum, preequatorial	Spindle-shaped	1/3	Tightly spiral	Preequatorial, far cephalad of cecal union

[a]Not considered valid genus by some scientists

German surgeon Theodor Bilharz who first discovered a human blood fluke in the portal veins of an Egyptian peasant in Cairo (Kasr El Aini) and named it *Distoma haematobium* (Distoma = name for flukes having two suckers or mouths; haematobium = responsible for hematuria). A new genus by the name *Bilharzia* was suggested by Cobbold in 1859 for this parasite in honor of its discoverer, but 3 months earlier Weinland (1858) had named it *Schistosoma* (cleaved body); hence, the parasite became *S. haematobium*.

Although Bilharz (1852), while studying bladder disease, encountered both terminal-spined and lateral-spined eggs, he regarded terminal-spined as normal and lateral-spined as deformed eggs of same fluke species. However, Manson (1903) reported lateral-spined eggs in the feces of a patient who had never suffered from hematuria or ever visited Africa, leading him to suggest that possibly there are two schistosome species—one with lateral-spined ova and other with terminal-spined ova (see Srivastava 1960). This was Sambon (1907) who, on the basis of distinctive characteristics of lateral-spined ova, their association with dysentery, and geographical distribution, created a new species of schistosome and named it *S. mansoni* in honor of Manson who had first suggested separation of the two species.

Discovery of *S. japonicum* from Japan is also interesting where Majima (1888), for the first time, reported that hepatic cirrhosis in man is produced by the eggs of an unknown trematode. Katsurada (1904) found characteristic eggs (of *S. japonicum*) in feces of five patients and suspected that the disease is caused by these eggs, and their adult worms may be present in the portal system. Instead of examining human cadavers, he examined cats and dogs of endemic areas and recovered several specimens of the blood flukes from the portal system of these animals and named it *S. japonicum*—a new species.

India was not behind in the discovery of schistosomes whose existence was noticed as early as 1882 by Cobbold and subsequently by Bomford (1886). However, this was Montgomery (1906) who described three new species from Indian domestic animals—*S. indicum* from equines, *S. spindalis* (later changed to *S. spindale*), and *S. bomfordi* (in honor of Dr. Bomford) from cattle of Mukteswar, U.P. (Tables 2.2 and 2.3). As the last species contained more than 16 testes, it was transferred by Price (1929) to *Ornithobilharzia* and subsequently to *Orientobilharzia* by Dutt and Srivastava (1961a) on the grounds discussed below.

A new type of schistosome egg was observed in human stools by Chandler (1926) near Calcutta, and since adult worms of these eggs were yet unknown, Chandler named the fluke *S. incognitum*. These typical eggs and adult flukes were recovered from pigs by Rao and Ayyar in 1933 in Madras who named the parasite as *S. suis*. This was considered synonymous to *S. incognitum* by Bhalerao (1938). Later, Sinha and Srivastava (1956) merged the two species, retaining *S. incognitum* as its valid name.

Nasal granuloma in Indian cattle is known since long. In 1932, its etiology was suspected to be a schistosome by Datta (1932). Malkani (1932) considered the parasite as a variant of *S. spindalis*. Bhalerao (1932) suggested that the parasite is *S. spindalis* and gave no significance to the site of infection, minor morphological variations

Table 2.2 Morphological fea ıres of *Schistos* ıa species preva ıt in India (all me ısurements in mı except eggs)

Description	*S. incognitum* Sinha and Srivastava (1956)	*S. indicum* Srivastava and Dutt (1962)	*S. nasale* Rao (1933, 1934)	Dutt (1967a)	*S. spindale* Montgomery (1906) Flukes from ruminants	Bhalerao (1932) Flukes from ruminants	Mishra (1991) Flukes from lab. animals	*S. haematobium* Gadgil (1963) Flukes from lab. animals
Male								
Length	2.43–8.86	4.1–19.85	6.3–11	6.72–11.57	4.5–12.2	5.6–13.5	2.5–11	8.5–11
Breadth	0.1–0.457	0.157–0.45		0.234–0.560	0.250–0.667	0.171–0.326		
Oral sucker	0.1–0.2 × 0.08–0.18	0.14–0.33 × 0.1–0.26	0.1	0.154–0.328 × 0.126–0.304	0.306 × 0.25	0.206–0.29 × 0.136	0.1–0.43	
Ventral sucker	0.085–0.26	0.16–0.4	0.12	0.192–0.395	0.2–0.357	0.18–0.32 × 0.04–0.12		
Number of testes	2–7	05–16	2–4	3–4	6–7	3–6	3–5	4
Size of testes				0.063–0.127 × 0.073–0.105	0.085	0.3–0.08 × 0.026–0.068		
Tegument	Highly tuberculated	Tuberculated	Tuberculated	Tuberculated	Tuberculated	Tuberculated and atuberculated	Atuberculated	Tuberculated
Female								
Length	2.57–7.57	4.93–26–42	5–11	6.91–11.71	7.17–14.1	7.18–16.2	2.23–11.12	9–12
Breadth	0.05–0.14	0.049–0.072		0.103–0.21	0.1–0.2	0.095–0.143	0.06–0.18	
Oral sucker	0.05–0.1 × 0.03–0.07	0.09–0.12 × 0.04–0.05		0.061–0.12 × 0.026–0.062	0.068	0.044–0.086 × 0.023		

Ventral sucker	0.03–0.057	0.04–0.06		0.026–0.05		0.037–0.48 × 0.016		
Length of paired intestine		2.75–13.3		3.12–5.92		2.8–8.8		
Common ceca		2.43–11.9	About 1/3 body length	2.95–5.72		4.19–6.93		
Position of ovary	Anterior third of body	Immediately behind middle of body	Postequatorial	Middle fifth	Postequatorial			Equatorial
Shape of ovary	Pyriform or spirally elongated	Cylindrical or with 3–4 constrictions						
Egg no. in uterus	1	1	1–5	1–2		Many	5–6	Many
Shape of egg	Suboval, flat at one side, asymmetrical spine at one end	Oval-shaped with terminal spine	Boomerang-shaped	Boomerang-shaped	Spindle-shaped	Spindle-shaped	Spindle-shaped	Oval with longer spine
Egg size	0.097–0.148 × 0.045–0.081	0.098–0.113–0.046–0.056	0.336–0.581 × 0.060–0.080	0.316–0.508 × 0.040–0.075	0.284–0.400 × 0.044–0.072			0.129–0.137 × 0.052–0.058

Table 2.3 Morphological features of *Orientobilharzia* and *Bivitellobilharzia* species prevalent in India

	O. bomfordi	*O. turkestanicum*	*O. dattai*	*O. harinasutai*	*Bivitellobilharzia nairi*
				Kruatrachue et al. (1965)	
Description	Montgomery (1906)	Bhalerao (1932)	Dutt and Srivastava (1961a)	Flukes from lab. animals	Sundaram et al. (1972)
Male					
Length	7.089	4.2–8	2.8–7.7	1.85–3.99	14.40–17.17
Breadth	0.408	0.34–0.476	0.1–0.32	0.15–0.37	0.7–0.9
Oral sucker	0.306	0.173–0.255	0.11–0.243	0.052–0.117	0.38
Ventral sucker	0.34	0.192–0.289	0.135–0.243	0.049–0.202	0.519
Number of testes	61	70–80	37–70	55–70	58–74
Size of testes	0.1 × 0.09		0.013–0.067 × 0.011–0.053	0.026–0.044 × 0.013–0.026	
Tegument	Tuberculated	Atuberculated	Atuberculated	Tuberculated	Tuberculated
Female					
Length	7.31	3.4–7.8	2.14–7.53	1.72–3.19	20.5–24.0
Breadth	0.172	0.086–0.112	0.06–0.13	0.06–0.1	0.45–0.51
Oral sucker	0.046	0.053–0.072	0.053–0.073	0.026–0.036	0.138–0.155
Ventral sucker	0.042	0.022–0.023	0.027–0.037	0.028–0.065	0.176
Length of paired intestine	1.819	1.73–1.93	1.5–4	Short	
Common ceca	5.109	3.56–5.36	1.3–3.07	Long	
Position of ovary	Anterior third	Anterior third	Middle fifth	Preequatorial	Anterior third
Shape of egg	Oval with terminal spine	Oval with leaflike appendage	Asymmetrically oval	Asymmetrically oval with lateral spine	Ovoid with asymmetrical sides
Egg size	0.125–0.136 × 0.053–0.060	0.108–0.135 × 0.042–0.048	0.12–0.17 × 0.043–0.060	0.111–0.127 × 0.027–0.052	0.141–0.181 × 0.066–0.108

in the ova, number of testes, and tubercles on the cuticle (perhaps, more confusion was by considering *S. spindale* being tuberculated, as mentioned by Montgomery). However, Rao (1933, 1934, 1935) did not agree with previous workers in considering it as being *S. spindale* on the basis of constant morphological differences (Table 2.2), and most importantly, his experiments proved that *S. spindale* cannot cause nasal granuloma. Thus, a new species *S. nasalis* (or *S. nasale*) was created by Rao (1933) which is unique in utilizing nasal blood vessels as its habitat. Ironically, it is *S. nasale* only which causes pathology in nasal cavity of the cattle; otherwise, birds harbor nasal schistosome species without much pathogenicity.

The discussion on *Schistosoma* species prevalent in India will be incomplete without mentioning the discovery of *S. haematobium* in hematuria cases of human beings in Gimvi village of Ratnagiri district, Maharashtra. Terminal-spined, oval-shaped schistosome eggs were recovered from this village in urine samples of humans who have never left the village in their lifetime, thereby confirming Gimvi village to be the origin of the infection. As the eggs closely resembled with those of *S. haematobium*, the investigators (Gadgil and Shah 1952) named the parasite *S. haematobium*. However, this claim of *S. haematobium* resulted in great controversy mainly because *S. haematobium* utilizes *Bulinus* species as its snail host which is not found in the Indian continent; hence, it was doubtful whether the fluke was *S. haematobium*. Gadgil (1963) presented information from the experts suggesting that the fluke was *S. haematobium*. But except for a similar location of the fluke in humans, like *S. haematobium,* it differed in geography and snail compatibility; infectivity experiments to local snails caused recovery of schistosome cercariae only from *Ferrissia tenuis* which has never been identified as an intermediate host to any schistosome species. Therefore, geographical distribution and snail host compatibility do not confirm the parasite to be *S. haematobium—t*he important criteria for speciation of schistosomes (Rollinson and Southgate 1987). To rest the controversy, Gaitonde et al. (1981) suggested the parasite as a variant of *S. indicum*. This assumption is even more wild and difficult to accept due to wide differences between this fluke and *S. indicum*; in Gimvi, it was not an accidental infection in one or two men, but the urinary tract of more than 30% humans were infected. Such a variant of *S. indicum* is not known particularly where *Indoplanorbis exustus* is also not implicated. But there is no way to further the research and to accumulate more details as the infection is now dead with remote chances of recovering any blood fluke from humans of that area. Looking at the scientific facts, it will be prudent to call the fluke *Schistosoma gimvicum* rather than *S. haematobium* or a variant *of S. indicum*.

The case of reporting *S. bovis* from India or South Asia is more intriguing. Bhalerao (1935) believed its presence in India and cited references of its occurrence from Bombay, U.P., Punjab, and Hyderabad. But its existence in India has also been rejected on grounds similar to that of *S. haematobium* or *S. japonicum*. Nevertheless, presence of *S. bovis* is suggested on the basis of egg morphology, whereas presence of latter two species was claimed on morphological studies of the cercariae and blood flukes; there are more chances of mistakes with cercariae and blood flukes than egg morphology. In his survey work on sheep, goat, and cattle in Jabalpur and Indore (Madhya Pradesh) and Nagpur and Amravati (Maharashtra), Moghe (1945) reported to have found *S. indicum*, *S. spindale*, *S. bovis*, and *S. haematobium* in these animals. There is no doubt that he confused *S. indicum* eggs with those of *S. haematobium;* but eggs of *S. spindale* and *S. bovis* are marked by the difference in their size, hence a lesser possibility of mistaken identity. These *S. bovis*–like eggs (Fig. 2.1) have again been encountered in albino mouse which were experimentally infected with wild schistosome cercariae (Agrawal and Sahasrabudhe 1988; see below).

More recently, Rajkhowa et al. (2005) made a survey of intestinal parasitism in Mithun (*Bos frontalis*) from Arunachal Pradesh, Manipur, Mizoram, and Nagaland. Among fluke infections, they have mentioned occurrence of *Fasciola*, *Fascioloides*, and *Paramphistomum* spp.; incidence of 2.7% of *S. indicum* and 5.4% of *S. bovis* is also mentioned by these workers. Occurrence of *S. bovis* in Mithun has also been claimed in eastern Bhutan (Win et al. 1991) and from cattle of Rabwah area of Pakistan (Anwar and Gill 1990). In all these reports, *S. indicum* was another blood fluke species existing in the bovines; interestingly, *S. spindale* has not been mentioned in these reports, though it is equally widespread in South Asia. Moreover, it appears that these workers were not aware about nonexistence of *S. bovis* in this geography or else a more detailed study would have been carried out by them; therefore, their reports cannot be accepted without further verifications. However, all these reports, including ours (Agrawal and Sahasrabudhe 1988) suggest the possibility of a schistosome species existing in South Asia whose eggs are *S. bovis*-like, but details are yet unknown. As per nomenclature of schistosome species, depending on the snail host and geography, it will be improper to call them *S. bovis.* Since these eggs are spindle-shaped but smaller in size, it may be more prudent to create a new species which is existing in South Asia with *S. bovis*-like eggs.

There are other species of *Schistosoma* which have been described from other countries. The taxonomy of *Schistosoma* is changing very fast as may be appreciated by the fact that WHO (1985) has mentioned existence of 16 valid species of *Schistosoma*, which has increased to 18 in 1987 (Rollinson and Southgate 1987) to 20 in 2003 (Lockyer et al. 2003) and to 22 till 2009. The 22 species of *Schistosoma* are *S. bovis*, *S. curassoni*, *S. edwardiense*, *S. guineensis*, *S. haematobium*, *S. hippotami*, *S. incognitum*, *S. indicum*, *S. intercalatum*, *S. japonicum*, *S.kisumuensis*, *S.leiperi*, *S. malayensis*, *S. mansoni*, *S. margrebowiei*, *S. mattheei*, *S. mekongi*, *S. nasale*, *S. ovuncatum*, *S. rodhaini*, *S. sinensium*, and *S. spindale.*

Amusingly, all the four Indian *Schistosoma* species (*S. indicum*, *S. spindale*, *S. incognitum*, and *S. nasale*) were discovered in India as early as 1933, and no new addition has been made since then (Table 2.2). Though during this ensuing period many epidemiological differences in schistosomiasis in different geographies of South Asia have been identified, yet taxonomic work has remained standstill since the last work of Dutt, creating a new genus and species of *Orientobilharzia dattai* (Dutt and Srivastava 1955). There is neither identification of new schistosome species nor confirmation of presence of schistosome strains from India or any other South Asian country despite the fact that at times mammalian schistosome cercariae of unknown origin have been recovered and also egg morphology as diverse as with

Fig. 2.1 *S. bovis*–like eggs in the uterus of *S. spindale* (?) female (Agrawal 1978)

lateral spine is recognized. This is partly because of dearth of taxonomists and partly due to complexity of the subject which can be resolved only by application of new molecular techniques.

2.1.1.2 Genus *Bivitellobilharzia*

This genus was created by Vogel and Minning (1940) for the schistosome they recovered from African elephants, naming it *Bivitellobilharzia loxodontae* n.g., n.sp. Nevertheless, when a schistosome was recovered from a cow elephant in the Topslip area of Coimbatore district in South India, it was named as *Schistosoma nairi* (Mudaliar and Ramanujachari 1945). The investigators were unaware about the discovery of *Bivitellobilharzia loxodontae* as they have mentioned "But no schistosome has so far been met with, in the elephant, either in India or elsewhere." As the number of testes was more than 16, Bhalerao (1947) transferred this species to the genus *Ornithobilharzia*. But presence of a pair of vitelline glands in females and a large number of testes in males resulted in its reallocation to the genus *Bivitellobilharzia* by Dutt and Srivastava (1955, 1961a). This parasite was redescribed by Sundaram et al. (1972) under the name *Bivitellobilharzia nairi* (Table 2.3).

2.1.1.3 Genus *Orientobilharzia*

This is the succession of genus *Ornithobilharzia* which was established by Odhner (1912) for an avian schistosome, *Ornithobilharzia intermedia* from *Larus fuscus*; some more avian schistosomes were transferred to this genus. Two mammalian schistosomes *Schistosoma bomfordi* (Montgomery 1906) and S. *turkestanicum*