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Clinical morbidity of single or mixed schistosome species infection in two communities of southern Malawi

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As part of a larger community-based epidemiological study entitled Hybridisation in Uro-Genital Schistosomiasis (HUGS), a parasite infection and clinical morbidity sub-study, implementing portable ultrasonography annually, was undertaken upon 701 participants from two communities in Mangochi and Nsanje Districts, southern Malawi. Our aim was to document the clinical morbidity a year after praziquantel treatment in those with previously proven human and/or zoonotic schistosomiasis, repeated a calendar year later after biannual praziquantel treatment. The median participant age was 12.0 years, with 293 (41.8%) having urinary *Schistosoma haematobium* egg-patent infections. Upon molecular analyses, these participants were co-infected with *S. mansoni* (29, 9.9%), *S. mattheei* (38, 13.0%), and six were infected with all three schistosome species occurring concurrently. A total of 166 participants (23.7%) had abnormal bladder wall thickness, 72 severely abnormal thickened bladder walls and 7 had bladder wall masses, among other abnormalities by ultrasonography. On the second annual follow-up, 203 participants were available (median age: 22.0 years), and of these, 27 (13.3%) presented

with urinary *S. haematobium* egg-patent infections, with 2 (1.0%) having *Schistosoma mansoni*, 8 (3.9%) having *Schistosoma mattheei* and 2 with all species concurrently. Of these, only six participants (3.0%) had severely abnormal thickened bladder walls and other abnormalities. Overall, greater morbidity was observed in those with *S. haematobium* alone than in those with mixed species infections.

'This article is part of the Royal Society Science+ meeting issue 'Parasite evolution and impact in action: exploring the importance and control of hybrid schistosomes in Africa and beyond'.

1. Introduction

Despite large-scale control with preventive chemotherapy, schistosomiasis remains a pervasive parasitic disease in sub-Saharan Africa (SSA), with more than 90% of the global disease burden there. While the chronic morbidity associated with organ-specific damage and fibrosis can be observed by point-of-contact portable ultrasonography, scale-up of this surveillance is still unfortunately out of reach for many national control programmes [1,2]. Across SSA, two dominant schistosome species occur, causing human urogenital *Schistosoma haematobium (Sh*) and intestinal *Schistosoma mansoni* (*Sm*) schistosomiasis, respectively. Both infections can be prevalent across much of SSA, with co-infections also arising [3–7]. In addition, schistosome species such as *Schistosoma bovis* (*Sb*), *Schistosoma curassoni* (*Sc*) and/or *Schistosoma mattheei* (*Smat*), which cause intestinal disease in animals, have been observed, particularly when additional veterinary surveillance has been reported [8–13]. Furthermore, some of these species, by themselves or upon hybridization with *Sh,* can cause zoonotic schistosomiasis in humans, such as *ShxSb* and *ShxSmat* hybrid forms, with host morbidities remaining to be better characterized clinically [14]. Hybridization is an emerging public health concern where cross-specific male and female schistosomes conjugate to pair up, mate and produce 'hybrid' progeny. Such offspring may change typical biological characteristics and facilitate introgressive evolution between species, thereby impacting upon schistosomiasis control and elimination plans.

In people, intestinal schistosomiasis is associated with hepatosplenomegaly, periportal fibrosis with portal hypertension, whereas urogenital schistosomiasis is characterized by haematuria, bladder cancer and various lesions within the urinary and reproductive systems [15–17]. Where co-infection of *Sh* and *Sm* has been noted, research has shown that in *Sh–Sm* infections, hepatosplenic morbidity appears lower than that with single *Sm* infection, but by contrast, urogenital morbidity appears raised in comparison with *Sh* alone. This may be explained by subtle differences in the egg-laying behaviour of adult worms. *Sh* males divert *Sm* females from the portal vein to the vesical plexus, resulting in fewer eggs in liver tissues but more eggs in bladder tissues [3–5,18]. Such behaviours of adult worms could probably occur in zoonotic and hybrid infections (i.e. *ShxSmat*), although the relative amounts of laid eggs might also differ owing to hybrid vigour and increased fecundity [19].

Computed tomography and magnetic resonance imaging are regarded as the 'gold' standard for detailed visualization of urinary/reproductive tract and liver morbidity [20]—in particular, for detection of egg-specific granulomata and calcifications [21–24]. Such methods are seldom available in point-of-care settings. Alternatively, portable ultrasonography is available and internationally recommended [25,26], particularly after the introduction of the WHO Niamey protocol, which offers operational guidelines describing schistosomiasis-associated lesions in the urinary tract and liver [27]. The pathologies have also been anecdotally observed to be correlated with clinical features specific to schistosomiasis and noted to resolve in earlier stages compared with being irreversible in late presentation [28,29]. Indeed, the ongoing improvements and reduction in price of the ultrasound machines, coupled with the rise in the numbers of competent sonographers, have resulted in this method gaining more significance and usage in disease surveillance activities of national control programmes in Africa.

As part of a larger community-based study funded by the National Institute for Health Research and Wellcome Trust UK, entitled 'Hybridisation in UroGenital Schistosomiasis (HUGS)', we aimed to shed new light on the clinical morbidity of human and zoonotic schistosomiasis [30]. To do so, we undertook a pilot sub-study on infection and morbidity, implementing portable ultrasonography in Mangochi and Nsanje Districts. Our objective was to better document clinical morbidity in 2023 (June/July), a year after praziquantel treatment, in those with previously proven human and/or zoonotic schistosomiasis, and then again another year later, in 2024 (June/July), after biannual praziquantel treatments.

2. Material and methods

(a) Study area, population and sampling

The pilot infection and clinical morbidity sub-study took place in the Mthawira community in Nsanje District along the Shire River and the Samama community in Mangochi District on the southern shoreline of Lake Malawi (electronic supplementary material, figure S1). Those identified with active egg-patent schistosomiasis in 2022 were invited for an examination by ultrasonography as a supplemental activity to the wider HUGS study follow-up in June 2023. Thereafter, a subsequent ultrasonography follow-up was conducted after 12 months in June 2024 [30]. Additional written informed consent was sought for the sub-study enrolment on each of the two occasions.

(b) Study data collection

The study methods utilized for the data collection included individual questionnaires, parasitological and molecular analyses of urine and stool samples collected in the community, as previously described [30,31]. The collected urine sample during the study visit was filtered and examined microscopically to detect *Schistosoma* eggs, recorded per 10 ml of urine, whereas heavy infection intensity was described at ≥50 eggs per 10 ml. Additionally, the urine underwent reagent dipstick testing and point-of-care circulating cathodic antigen (POC-CCA) analysis for the detection of intestinal schistosomiasis. Stool samples of those with positive POC-CCA tests underwent Kato–Katz testing. These samples were subsequently preserved in 1 ml of 70% ethanol before molecular High-Resolution Melt and TaqMan® real-time PCR analyses for *Schistosoma* spp.

Afterwards, transabdominal and pelvic ultrasonography was conducted using a portable SIUI Digital Ultrasound Imaging System, with a 3.5 MHz probe (Shantou Institute of Ultrasonic Instruments Co. Ltd., #77 Jinsha Road, Shantou, Guangdong 515041, China) (electronic supplementary material, figure S2). This was to assess pathological abnormalities in the urinary bladder, kidneys, spleen, liver and genital organs in females (uterus, fallopian tubes and ovaries) and males (prostate, seminal vesicles, testes and epididymis), as previously described [32] and highlighted below.

(c) Preparations for the ultrasonography procedure

Safety precautions were taken into consideration during the ultrasonography examinations. Apart from briefing participants on the ultrasonography procedure, they were asked to present with a full bladder to increase the quality of the images.

(d) Outline of the ultrasonography procedure

The participant was positioned supine on the examination couch. The scanning procedure investigated the urinary bladder, kidneys, spleen, liver and genital organs (uterus, fallopian tubes, ovaries, prostate, seminal vesicles, scrotum (testis, epididymis)). Image quality was recorded first, and then the absence/presence of pathological findings was documented.

(e) Urinary bladder and kidneys

Transverse (TS) and longitudinal (LS) sweeps through the bladder were performed to assess the shape (distension) and wall thickness, as well as the distal ureters, where possible. Schistosomiasis-related bladder pathologies included a rounded or irregular shape, wall thickening with diffused or focal thickening of >5 mm (mild: 6–10 mm; severe: ≥11 mm), wall calcifications, masses or pseudopolyps protruding into the bladder lumen.

Bladder wall thickness was measured in mm and stored as a separate still image. For any pathological findings, additional still images with relevant measurements were stored. The kidneys were scanned for any abnormalities, including evidence of hydronephrosis.

(f) Uterus, fallopian tubes, ovaries and surrounding structures

The uterine size, shape, orientation and abnormalities (fibroids, polyps, masses) were assessed and documented in both LS and TS planes. The endometrium, its thickness, myometrium and cervix were carefully evaluated, and their appearances were documented. Myometrial masses and contour abnormalities were recorded. The ovaries' size and number, and the presence of any cysts or tumours, as well as the fallopian tubes, were assessed.

(g) Prostate, seminal vesicles and scrotum

The prostate was visualized during scanning of the bladder. Pathological findings included nodules, masses and calcifications of the prostate. The best representative sweep was stored under the label 'prostate', and for any pathological findings, additional still images were stored. Seminal vesicles were scanned in the TS plane with normal appearances being symmetrical, measuring 15 mm or less, with a smooth outline. Pathological findings were enlarged and/or asymmetrical vesicles with a nodular, hyperechoic appearance. Vesicles measuring larger than 15 mm were stored as a separate still image, while for any other pathologic findings, additional still images were stored. The scrotum was scanned to assess both testes for nodules, calcifications or any other abnormalities, in addition to the epididymis and vas deferens.

(h) Disinfection and patient information after the completion of the procedure

At the end of the procedure, the scanner probe was cleaned and disinfected accordingly. All participants were notified of pathological findings, and appropriate management was provided in accordance with the standard clinical practice. Thereafter, praziquantel treatment at 40 mg kg^{-1} as a single dose was offered.

Table 1. Demographic information of the study participants.

variable		all	Mangochi	Nsanje
participants	*number*	701	507	194
	%	100	72.3	27.7
age	*range*	2–68	2–47	3–68
	median	12	12	14
sex	*emale (%)*	375 (53.5)	263 (51.9)	112 (57.7)
	male (%)	326 (46.5)	244 (48.1)	82 (42.3)

(i) Statistical analyses

All the information collected during the study was entered into Microsoft Excel and SPSS computer packages. All video clips and digital images were stored safely for further analyses, while some images were randomly selected and re-read for quality control. The data collected from the clips, images and report forms were screened to clear all errors using descriptive analyses, and cleaning was conducted before commencing statistical analyses to present the results of the study.

(j) Ethical considerations

Ethical approval for the study was granted by the College of Medicine Research Ethics Committee (COMREC), Kamuzu University of Health Sciences (KUHeS), Malawi (approval number: P.08/21/3381), and the Liverpool School of Tropical Medicine (LSTM) Research Ethics Committee (LSTM REC) in the United Kingdom (registration number: 22-028). Utmost privacy and confidentiality were maintained in the study, and where necessary, the information was anonymized to protect the identity of the participants. After notification of the ultrasonography results, further appropriate investigations and management were conducted in accordance with the standard clinical practice, together with praziquantel (PZQ) treatment at 40 mg kg^{-1} as a single dose.

3. Results

In 2022, a total of 1964 participants were recruited to participate in the wider HUGS survey, with 1789 followed up in 2023 and 1908 in 2024 surveys. The majority of participants (55.2%) were from Mangochi, while 44.8% were from Nsanje. Females comprised 55.7% of the study participants, and males comprised 44.3%. The overall prevalence of urogenital schistosomiasis obtained in 2022 was 43.6%, with Mangochi having the higher prevalence of 51.5% and Nsanje having a prevalence of 34.3%. The rate of heavy-intensity infections in 2022 was 10.5%.

Since ultrasonography was conducted during the annual follow-up human survey in 2023, of the 856 eligible participants with egg-patent schistosomiasis identified in 2022, 701 underwent the procedure in 2023, with the majority from Mangochi District (507, 72.3%; table 1). More females had ultrasonography (375, 53.5%) than males (326, 46.5%). The median age of the participants was 12 years (range: 2–68 years), similar to Mangochi participants (12 years, range: 2–47), while it was higher for Nsanje District participants (14 years, range: 3–68).

Regarding the ultrasonographic findings, 166 participants (23.7%) had abnormal bladder wall thickness (table 2) and 72 (10.3%) had severely abnormal thickened bladder walls, above 11 mm, with 7 having bladder wall masses, which could possibly be cancer (figure 1).

Abnormalities were observed in kidneys (55, 7.8% had hydronephrosis), spleen (41, 5.8%) and liver (56, 8.0%), with 27 having various grades of fibrosis. In addition, abnormalities were observed in the genital organs, mainly calcifications. For females, the abnormalities were in the uterus (26, 3.7%), ovaries (8, 1.1%) and fallopian tubes (8, 1.1%), while in males, these were present in the prostate (4, 0.6%), seminal vesicles (3, 0.4%), epididymis (4, 0.6%) and testis (6, 0.9%), with 17 (2.4%) having hydroceles (figure 2).

Regarding the schistosome infection, 293 participants (41.8%) were observed to have *Sh* eggs in their urine at the first ultrasonography visit in 2023, with more females (157, 53.6%) than males, and their median age was 11 years old (range: 3–51). Seventy-five participants (25.6%) had abnormal thickness of the bladder wall, of whom 38 had severely abnormal bladder thickness with 4 masses (table 3). Twenty-one participants (7.2%) had hydronephrosis. Other abnormalities observed among those participants with *Sh* infection were in the spleen (16), liver (23, with 13 having fibrosis), uterus (7), ovaries (1), fallopian tubes (2), prostate (4), seminal vesicles (2), epididymis (1) and testis (1), with 6 having hydroceles (figure 3).

Using PCR, 29 participants (9.9%) had *Sm* detected in their urine, with more females (15, 51.7%) than males, and their median age was 12 years old (range: 3–19). Of these, four participants had *Sh* and *Sm* eggs on urine microscopy with heavy infection intensity. Two of the 29 had only the *Sm* infection detected on PCR. Ten of the participants with *Sm* infection (34.5%) had abnormal thickness of the bladder wall, of which four had severely abnormal bladder thickness, two having hydronephrosis. Other abnormalities observed were in the spleen (2), liver (1 fibrosis) and uterus (1).

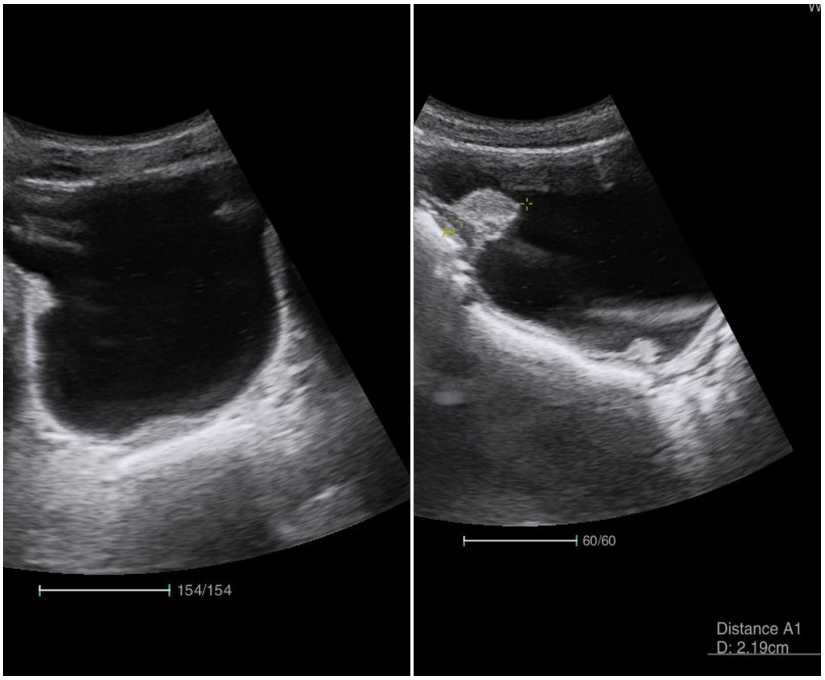

Figure 1. Severely abnormal urinary bladder wall thickening with polypoid mass in a 42-year-old female participant, with high-intensity *S. haematobium* infection only, detected on ultrasonography at the first annual follow-up survey in 2023.

Table 2. Description of abnormalities observed among the study participants during the first ultrasonography visit in June 2023.

Variable		All (*n*, %)	Comments
bladder	abnormal	166 (23.9%)	
	>11 mm	72 (10.3%)	masses (7)
kidneys	hydronephrosis	55 (7.8%)	bilateral (24)
spleen	abnormal	41 (5.8%)	—
iver	abnormal	56 (8.0%)	starry sky (25), pipe stem (6) fibrosis with ruff (1)
uterus	abnormal	26 (3.7%)	nodules/masses (2)
ovaries	abnormal	8 (1.1%)	masses (5), cysts (3)
fallopian tubes	abnormal	8 (1.1%)	masses (3) with 1 calcified
prostate	abnormal	4 (0.6%)	—
seminal vesicles	symmetry	3 (0.4%)	—
testis	abnormal	6 (0.9%)	calcifications (2)
epididymis	abnormal	7 (1.0%)	right (4), bilateral (3)
hydrocele	present	17 (2.4%)	bilateral (12), right (3), left (2)

Furthermore, 38 participants (13.0%) had *Smat* detected on PCR in their urine, with fewer males (14, 36.8%) than females, and their median age was 10 years old (range: 4 – 27). Of these, six participants had mixed infections of *Sh, Sm* and *Smat* (table 4), with one having lots of calcified eggs and another *Sm* eggs in urine; their median age was 12 years old (range: 10–16). Two of the 38 (5.3%) with *Smat* on PCR had no *Sh* eggs in urine. Six participants (15.8%) had abnormal thickness of the bladder wall, of which four (10.5%) had severely abnormal bladder thickness, with one having a bladder mass. Other abnormalities observed were in the kidneys (4 (10.5%) had hydronephrosis), spleen (2, 5.3%) and liver (2, 5.3%). Notably, one participant with a mixed infection had severely abnormal bladder wall thickness with bilateral hydronephrosis.

During the second annual follow-up in June 2024, 203 participants were available for ultrasonography; their median age was 22 years (range: 4–56 years). Slightly more participants were seen in Mangochi (102, 50.2%), with more females (134, 66.0%) than males undergoing the procedure. Only six participants (3.0%) had abnormally thickened bladder walls, with more than 11 mm of severe polypoid/flat thickness. Other abnormalities observed were in the kidneys (4 had hydronephrosis), spleen (13), uterus (6), ovaries (2, cysts/masses), prostate (3, nodules), with 4 having hydroceles.

Twenty-seven participants (13.3%) had *Sh* eggs in their urine; their median age was 19 years (range: 4–40), and more females (19, 70.4%) than males were scanned. Two participants (7.4%) had abnormal, severely abnormal bladder wall thickness of more than 11 mm and two had hydronephrosis. Other abnormalities were observed in the spleen (1) and uterus (3) only. Only two female participants with *Sh* eggs (1.0%) in their urine had *Sm* detected on PCR, and their average age was 17 years (range:

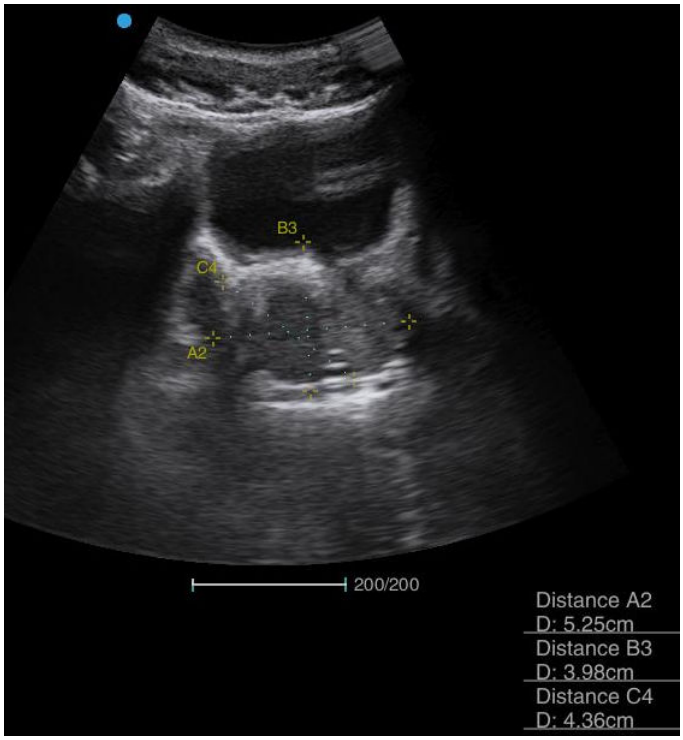

Figure 2. Prostate abnormality in a 34-year-old male participant, with heavy intensity *S. haematobium* infection only, detected on ultrasonography at the first annual follow-up survey in 2023.

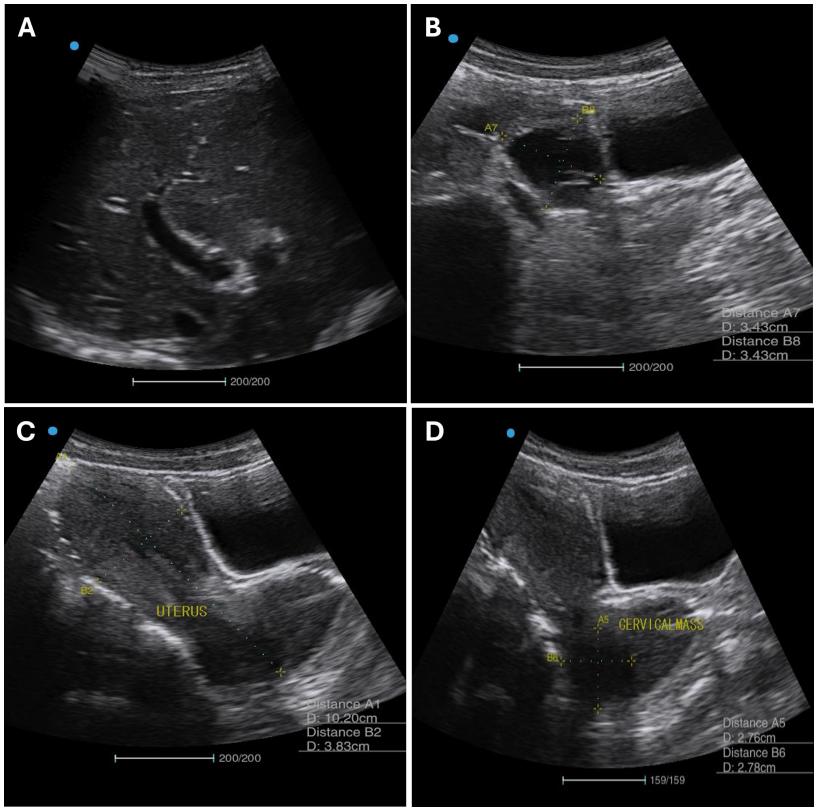

Figure 3. Abnormalities observed in the liver (A), right ovary (polycystic mass, B) and uterine cervix (enlarged with a mass, C and D) in a 27-year-old female participant, with *S. haematobium* infection only, detected on ultrasonography at the first annual follow-up survey in 2023.

14–20). The 20-year-old participant had a severely abnormal thickened bladder wall of more than 11 mm and an abnormality in the uterus, while the younger 14-year-old participant had left hydronephrosis.

Eight participants (3.9%) had *Smat* detected on PCR in their urine, with more females (6, 75.0%) than males, and their median age was 19 years old (range: 9–38). Only one participant had mixed infections of *Sh, Sm* and *Smat*. One participant (12.5%) had a severely abnormal thickened bladder wall of more than 11 mm. Other abnormalities observed were in the kidneys (3 had hydronephrosis), prostate (1, nodules) and one had left hydrocele. Overall, morbidity on ultrasonography was more frequently observed in those with *Sh* alone than in those with mixed species infections across all the time points.

Table 3. Description of abnormalities observed on ultrasonography among study participants with *S. haematobium* infection during the visit in June 2023.

variable		all (*n*, %)	comments
	abnormal	75 (25.6%)	
bladder	*>11* mm	38 (13.0%)	masses (4)
kidneys	*hydronephrosis*	21 (7.2%)	bilateral (8)
spleen	*abnormal*	16 (5.5%)	—
liver	*abnormal*	23 (7.8%)	starry sky (13), pipe stem (1), fibrosis with ruff (1)
uterus	*abnormal*	7 (2.4%)	—
ovaries	*abnormal*	1 (0.3%)	right polycystic mass
fallopian tubes	*abnormal*	2 (0.7%)	calcifications (1)
prostate	*abnormal*	4 (1.4%)	—
seminal vesicles	*symmetry*	2 (0.7%)	—
testis	*abnormal*	1 (0.3%)	bilateral
epididymis	*abnormal*	1 (0.3%)	bilateral enlargement
hydrocele	*present*	6 (2.0%)	bilateral (4), right (1), left (1)

Table 4. Description of abnormalities observed on ultrasonography among study participants with *S. mattheei* infection during the visit in June 2023.

Variable		All	Comments
bladder	abnormal	6 (15.8%)	—
	>11 mm	4 (10.5%)	mass (1)
kidneys	hydronephrosis	4 (10.5%)	bilateral (1)
spleen	abnormal	2 (5.3%)	—
liver	abnormal	2 (5.3%)	starry sky (2)

4. Discussion

To our knowledge, this is the first prospective ultrasonographic study in Malawi and southeastern Africa to describe the clinical morbidity associated with schistosomiasis as caused by schistosomes of zoonotic, mixed and possibly hybrid species in the local community of people living along Lake Malawi in Mangochi District and along the Shire River in Nsanje District. Our study on the first annual follow-up survey among 701 participants who underwent the procedure observed significant abnormalities in the urinary bladder, kidneys, spleen, liver, female and male genital organs, mostly in females and those in the younger ages (median age: 12 years). Also, a higher number of participants had *Sh* infection (41.8%), in comparison with *Sm* (9.9%) and *Smat* (13.0%).

The majority of the abnormalities observed were in the urinary bladder and kidneys, namely abnormal bladder wall thickening, severe polypoid masses and associated bilateral hydronephrosis, which are mostly associated with urogenital schistosomiasis, while liver abnormalities were also observed, as shown in tables 2 and 3. The observed abnormalities on ultrasonography were also in very young participants, preschool-aged children and school-aged children (SAC), as previously seen [33].

As stated earlier and widely described in the literature, frequent exposure to infective cercariae-harbouring freshwater bodies in the local communities causes schistosome infection. The eggs shed by female schistosomes are trapped within the tissues, inducing immunological reactions and granulomata formation and resulting in pathological lesions observed in urogenital, hepatosplenic and intestinal organs, thereby compromising these organs' functioning [16,17,34]. Early diagnosis and management are critical in preventing such chronic and ultimately fatal consequences of schistosomiasis.

Lesions associated with schistosomiasis can be detected using radiological techniques that can aid the diagnosis of liver and urological schistosomiasis, especially when associated with chronic complications [20–25,32]. Ultrasonography is one of the most safe and least-invasive tools for diagnosis, management and monitoring control of schistosomiasis and other neglected [22,28,35]. Portable, high-quality scanning devices can be easily transported to remote, rural, limited-resource endemic areas to assist in the detection of these abnormalities and the management of the disease.

Interestingly, schistosome worms have been thought to similarly reside in venous plexus around the genital organs such as uterus, fallopian tubes, ovaries, prostate, seminal vesicle and testes, resulting in echogenic lesions, calcifications, organ enlargement and hydroceles, among others [29,32,36], which can be detected by ultrasonography as observed in this study.

Furthermore, abnormalities were observed in participants with single *Sm* and *Smat* infections, as well as with mixed *Sh–Sm* and *Sh–Sm–Smat* infections, although at lower levels compared with the single *Sh* infection. As indicated earlier, research across SSA has found that *Sh–Sm* co-infections result in lower hepato-splenic morbidity compared with single *Sm* infections, but they

cause increased urogenital morbidity as compared with single *Sh* infections because dominant *Sh* males divert *Sm* females from the portal vein to the vesical plexus, resulting in fewer eggs in liver tissues but more eggs in bladder tissues [3–5,18].

Co-infections with more than one parasite are the norm within humans and animals [37], and encountering new infections of both human and animal origin results in synergistic or antagonistic interactions within the infected host [38]. Hybridization among parasites, specifically with zoonotic potential, is a major emerging public and veterinary health concern at the interface of evolution, epidemiology, ecology and control. It represents a significant, but previously ignored, issue for the monitoring and evaluation of morbidity during mass drug administration programmes and a significant challenge to the WHO targets towards elimination of schistosomiasis as a public health problem by 2030 [39]. Though not detected among these study participants, the possibility of such hybrid infections cannot be understated.

Monitoring of disease morbidity is critical in controlling the disease and preventing severe irreversible pathological abnormalities, which later could contribute to mortality. As a mainstay treatment, PZQ has been shown to be effective in treating both forms of schistosomiasis, registering cure rates of over 90% in most endemic areas [40,41]. Being utilized by most national control programmes in endemic areas as one of the key control interventions through the MDA campaigns, this has commonly targeted SAC, leaving out adults.

From the second annual follow-up survey after PZQ treatment, fewer pathological abnormalities were detectable in the participants, which could suggest that early mild abnormalities will be resolved by standard PZQ treatment it kills those adult-laying worms, hence reducing further damage to the organs [17]. Other chronic abnormalities, such as hydroceles, require further assessments and surgical interventions to resolve these at a larger, capable health facility.

Repeated exposure to infested lake water can contribute to new abnormalities developing after PZQ treatment [32]; therefore, repeated PZQ treatment is required for the prevention of chronic sequelae. In addition, the provision of adequate awareness and health education, portable, safe and clean water, encouragement of the construction and utilization of sanitation facilities and environmental control to reduce intermediate snail host populations are all important schistosomiasis prevention measures.

5. Conclusion

In conclusion, pathological abnormalities observed in participants with clinical morbidity associated with schistosomiasis, as caused by human and zoonotic schistosomes, can be detected on ultrasonography. A greater number and diversity of lesions in the urinary system were observed as compared with hepatosplenic, intestinal and genital systems. Further control and management interventions are required to include animal schistosome species in order to eliminate schistosomiasis as a public health problem in Malawi. To do so, the development of a One Health approach, integrating human, veterinary and ecological interventions, is needed.

Ethics. Ethical approval for the study was granted by the COMREC, KUHeS, Malawi (approval number: P.08/21/3381) and the LSTM REC in the United Kingdom (registration number: 22-028). Written informed consent and assent were obtained from the participants before recruitment into the study. Utmost privacy and confidentiality were maintained in the study, and, where necessary, the information was anonymized to protect the identity of the participants. The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional guides on the care and use of vertebrates.

Data accessibility. The data supporting this article have been included within the text.

Supplementary material is available online [42].

Declaration of AI use. We have not used AI-assisted technologies in creating this article.

Authors' contributions. S.A.K.: conceptualization, data curation, formal analysis, investigation, methodology, project administration, resources, supervision, validation, visualization, writing—original draft, writing—review and editing; L.K.: data curation, formal analysis, investigation, methodology, validation, visualization, writing—review and editing; B.M.: investigation, methodology, writing—review and editing; D.K.: methodology, supervision, writing—review and editing; L.C.: formal analysis, investigation, methodology, resources, validation, writing—review and editing; D.L.: data curation, formal analysis, investigation, methodology, writing—review and editing; P.C.: formal analysis, investigation, methodology, writing—review and editing; D.K.: formal analysis, investigation, methodology, writing—review and editing; G.N.: data curation, resources, writing—review and editing; A.C.: investigation, writing—review and editing; T.N.: investigation, writing—review and editing; E.C.: data curation, formal analysis, investigation, methodology, validation, visualization, writing—review and editing; B.N.: data curation, formal analysis, investigation, methodology, validation, visualization, writing—review and editing; G.C.: project administration, resources, supervision, writing—review and editing; H.C.: project administration, resources, supervision, writing—review and editing; V.K.: project administration, resources, supervision, writing—review and editing; A.J.: investigation, methodology, resources, writing—review and editing; S.J.: investigation, methodology, project administration, resources, writing—review and editing; R.C.: investigation, methodology, resources, writing—review and editing; J.A.: formal analysis, investigation, methodology, project administration, resources, validation, writing—review and editing; A.M.O.-F.: formal analysis, investigation, methodology, resources, validation, writing—review and editing; S.R.: formal analysis, investigation, methodology, resources, visualization, writing—review and editing; A.N.: resources, supervision, writing—review and editing; J.C.: resources, supervision, writing—review and editing; M.L.: resources, supervision, writing—review and editing; H.K.: resources, supervision, writing—review and editing; P.M.: conceptualization, project administration, resources, supervision, writing—review and editing; J.LaC.: conceptualization, funding acquisition, project administration, resources, supervision, writing—review and editing; R.S.: conceptualization, data curation, formal analysis, funding acquisition, investigation, methodology, project administration, resources, supervision, validation, visualization, writing—review and editing; J.M.: conceptualization, data curation, formal analysis, funding acquisition, investigation, methodology, project administration, resources, supervision, validation, visualization, writing—review and editing.

All authors gave final approval for publication and agreed to be held accountable for the work performed therein.

Conflict of interests. We declare we have no competing interests.

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