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Research Article

Molecular Epidemiology and Benzimidazole Resistance Screening of Ascaris lumbricoides and Trichuris trichiura in School-Aged Children

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Abstract

Preventive chemotherapy using single-dose albendazole or mebendazole is the cornerstone of soil-transmitted helminth (STH) control, raising concerns about the emergence of beta-tubulin resistance mutations in human-infecting nematodes. In this study, we assessed cure rates, egg reduction rates (ERR), and beta-tubulin single nucleotide polymorphisms in Ascaris lumbricoides and Trichuris trichiura following albendazole administration. Stool samples from 480 schoolchildren were examined by duplicate Kato-Katz smears before and 14 days after a single 400 mg dose of albendazole. Baseline prevalence was 28.5 percent for A. lumbricoides and 19.6 percent for T. trichiura. Albendazole achieved a high cure rate (94.2 percent) and ERR (98.6 percent) against A. lumbricoides, but showed suboptimal efficacy against T. trichiura (cure rate = 38.3 percent; ERR = 61.4 percent). Pyrosequencing of beta-tubulin codons 167, 198, and 200 on 120 T. trichiura and 140 A. lumbricoides egg DNA extracts revealed the F200Y resistance polymorphism in 18.3 percent of post-treatment T. trichiura samples compared to 4.2 percent pre-treatment, whereas A. lumbricoides remained 100 percent wild-type. Selection of F200Y mutant alleles contributes to reduced albendazole efficacy against T. trichiura. Co-administering ivermectin with albendazole is recommended to improve T. trichiura clearance and delay anthelmintic resistance.

Keywords: Trichuris trichiura, Ascaris lumbricoides, Albendazole efficacy, Beta-tubulin F200Y, Soil-transmitted helminths

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1. Introduction

Soil-transmitted helminths (STH) remain among the most prevalent neglected tropical diseases, with more than a quarter of the world population at risk of infection with Ascaris lumbricoides, Trichuris trichiura, and the hookworms Ancylostoma duodenale and Necator americanus (Jourdan et al., 2018). School-aged children bear a disproportionate share of this burden because of frequent soil contact, hand-to-mouth behaviour, limited access to safe water and sanitation, and age-dependent immunity. Chronic infection contributes to malnutrition, iron-deficiency anaemia, impaired growth and cognition, reduced school attendance, and diminished quality of life, even when worm burdens are classified as light by egg-count thresholds (Bethony et al., 2006; Jourdan et al., 2018). In endemic communities in sub-Saharan Africa, co-infection with A. lumbricoides and T. trichiura is common, and the two parasites are often targeted together by the same preventive chemotherapy programme, even though their biology, intestinal niche, and drug susceptibility differ in important ways.

Ascaris lumbricoides is a large intestinal roundworm that lives in the small intestine, where ingested eggs hatch, larvae migrate through the liver and lungs, and adults establish and produce large numbers of eggs that are excreted in stool. Trichuris trichiura, the human whipworm, lives in the caecum and ascending colon, with its thin anterior end embedded in the mucosa and its thicker posterior end free in the lumen. This anatomical difference matters for chemotherapy: drug delivered orally reaches high concentrations in the small intestine but lower and more variable concentrations in the large intestine, where T. trichiura resides (Diawara et al., 2013; Moser et al., 2017). The long pre-patent period, high fecundity of Ascaris, and the relative longevity of adult Trichuris mean that prevalence can rebound quickly after treatment if environmental contamination is not reduced, a pattern repeatedly documented in school-based cohorts followed after mass drug administration (MDA).

Since the London Declaration and the World Health Organization (WHO) roadmap for neglected tropical diseases, preventive chemotherapy — the periodic administration of single-dose albendazole (400 mg) or mebendazole (500 mg) to at-risk populations without prior diagnosis — has been the cornerstone of STH control (World Health Organization, 2017; World Health Organization, 2020). WHO recommends annual treatment where baseline prevalence of any STH infection is 20–50% and biannual treatment where prevalence exceeds 50%, with the goal of reducing moderate- and heavy-intensity infections in preschool- and school-aged children to below 1% (World Health Organization, 2017). This strategy has delivered large-scale reductions in morbidity and is widely regarded as one of the most cost-effective public-health interventions available. However, its very success creates a biological tension: repeated exposure of large parasite populations to a single drug class, often at sub-curative doses for one species, imposes strong selection pressure for drug-resistant genotypes, while cure is rarely verified at the individual level.

Benzimidazoles act by binding to parasite β-tubulin, preventing microtubule polymerisation and thereby disrupting cell division, intracellular transport, and glucose uptake. In veterinary nematodes, resistance is strongly associated with single nucleotide polymorphisms (SNPs) in the β-tubulin isotype 1 gene at codons 167 (F167Y), 198 (E198A), and 200 (F200Y) (Kwa et al., 1994; Diawara et al., 2009). These mutations reduce benzimidazole binding and have been selected repeatedly in livestock parasites exposed to frequent benzimidazole treatment. Whether the same mechanism threatens human STH control has been debated, because human MDA uses lower treatment frequency, incomplete coverage, and a large untreated reservoir (refugia) that can dilute resistant alleles. Nevertheless, early molecular surveys demonstrated that the F200Y polymorphism exists in human T. trichiura and that its frequency can increase after albendazole treatment (Diawara et al., 2013). Subsequent studies using pyrosequencing, SmartAmp2, and

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deep amplicon sequencing have reported variable frequencies of F167Y, E198A, and F200Y in T. trichiura and, less consistently, in A. lumbricoides, raising the possibility that continued single-drug pressure will progressively enrich resistant genotypes (Diawara et al., 2009; Rashwan et al., 2016; Zuccherato et al., 2018).

The therapeutic gap for T. trichiura is now well documented. Systematic reviews and network meta-analyses report that single-dose albendazole achieves cure rates above 90% and egg reduction rates (ERR) above 95% for A. lumbricoides, but cure rates of only about 30–50% and ERR below 80% for T. trichiura (Moser et al., 2017; Vaz Nery et al., 2024). This gap is not merely a pharmacodynamic curiosity: children who remain egg-positive after treatment continue to contaminate the environment, sustain transmission, and may experience ongoing morbidity. The gap also complicates monitoring and evaluation, because programme success measured by Ascaris outcomes can mask persistent Trichuris transmission. Combination therapy, particularly co-administration of ivermectin (200 µg/kg) with albendazole, has shown substantially higher efficacy against T. trichiura in randomised trials in Côte d'Ivoire, Laos, Pemba Island, and Uganda, and WHO now endorses this combination where feasible (Moser et al., 2018; Hürlimann et al., 2022; World Health Organization, 2023). A fixed-dose albendazole–ivermectin co-formulation has also advanced through clinical development, offering a practical route to combination preventive chemotherapy (Welsche et al., 2025).

Against this background, the present study was designed to answer three linked questions in a school-aged population: (i) what is the baseline prevalence and intensity of A. lumbricoides and T. trichiura before treatment; (ii) how efficacious is single-dose albendazole against each species when measured by both cure rate and ERR at day 14; and (iii) does albendazole treatment select for β-tubulin resistance-associated SNPs at codons 167, 198, and 200, and does that selection differ between species? We hypothesised that albendazole would be highly efficacious against A. lumbricoides but suboptimal against T. trichiura, and that post-treatment T. trichiura survivors would be enriched for F200Y, consistent with drug selection rather than random survival. Testing this hypothesis in paired pre- and post-treatment samples, using standardised Kato-Katz parasitology and quantitative pyrosequencing, provides evidence that is directly actionable for control programmes: if selection is confirmed, programmes cannot rely on albendazole alone for Trichuris control and should accelerate the transition to combination therapy and molecular surveillance.

2. Materials and Methods

2.1 Study design, setting, and participants

This was a prospective, school-based, single-arm treatment efficacy and molecular surveillance study conducted in primary schools in an STH-endemic area of Kenya, selected because prior district surveys reported STH prevalence above the WHO threshold for annual preventive chemotherapy (World Health Organization, 2017). Schools were selected in consultation with county health and education authorities to include both rural and peri-urban catchments with varied water, sanitation, and hygiene (WASH) conditions. Children aged 5–14 years enrolled in participating schools were eligible if they provided assent and their parent or guardian provided written informed consent, had resided in the area for at least six months, and had not received anthelmintic treatment in the preceding three months. Children with severe acute illness, known allergy to benzimidazoles, or chronic disease requiring ongoing medication were excluded and referred for care. Ethical approval was obtained from the University of Nairobi Ethics and Research Committee and the county health directorate, and the study was conducted in accordance with the Declaration of Helsinki. A total of 480 children were enrolled, a sample size calculated to estimate a baseline T. trichiura prevalence of about 20% with 5% precision at 95% confidence,

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allowing for 15% loss to follow-up and for sufficient post-treatment egg-positive samples for molecular analysis, following WHO efficacy monitoring guidance (World Health Organization, 2020).

2.2 Sample collection and Kato-Katz examination

A single fresh stool sample was collected from each child at baseline (day 0) and again 14 days after treatment (day 14), using labelled, leak-proof containers distributed the previous afternoon with pictorial instructions. Samples were transported in cool boxes to the field laboratory within four hours and processed the same day. Duplicate Kato-Katz thick smears were prepared from each sample using the WHO-recommended 41.7 mg template, cellophane coverslips pre-soaked in glycerol–malachite green, and standard clearing times (Katz et al., 1972; World Health Organization, 2020). Two independent microscopists, blinded to each other's results and to treatment status at baseline, counted eggs for A. lumbricoides and T. trichiura. Discrepant counts differing by more than 10% were resolved by a third senior microscopist. Egg counts were expressed as eggs per gram of stool (EPG) by multiplying the mean of duplicate smears by 24. Infection intensity was classified according to WHO thresholds: for A. lumbricoides, light 1–4,999 EPG, moderate 5,000–49,999 EPG, and heavy ≥50,000 EPG; for T. trichiura, light 1–999 EPG, moderate 1,000–9,999 EPG, and heavy ≥10,000 EPG (World Health Organization, 2020). Quality control included daily calibration of templates, random re-reading of 10% of slides, and external review of a subset at the University of Nairobi reference laboratory. Children found positive for any STH at baseline were treated, and those positive at follow-up were offered rescue treatment according to national guidelines.

2.3 Treatment and follow-up

All enrolled children received a single directly observed oral dose of albendazole 400 mg at baseline, administered by a study nurse after a light snack, in line with WHO preventive chemotherapy recommendations (World Health Organization, 2017). Adverse events were actively solicited at 30 minutes, 24 hours, and at the day-14 visit using a standardised symptom checklist covering abdominal pain, nausea, vomiting, diarrhoea, headache, dizziness, and fever. Serious adverse events were to be reported within 24 hours to the ethics committee and the county pharmacovigilance officer; none occurred. Loss to follow-up was minimised by school visits, teacher liaison, and household tracing for absentees. The 14-day follow-up window was chosen because it balances the need to allow expulsion of adult worms and clearance of eggs against the risk of reinfection and the WHO-recommended 14–21-day window for efficacy assessment (World Health Organization, 2020; Moser et al., 2017). Children who missed the day-14 visit were visited once more within three days; those still absent were classified as lost to follow-up and excluded from per-protocol efficacy analysis but retained for baseline prevalence estimation.

2.4 DNA extraction and β-tubulin pyrosequencing

For molecular analysis, a 2-g aliquot of each stool sample was preserved in 70% ethanol and stored at −20 °C until extraction. Egg DNA was extracted from 120 T. trichiura-positive and 140 A. lumbricoides-positive samples, selected to include both pre- and post-treatment specimens with sufficient egg counts for reliable amplification. Extraction followed a commercial stool DNA kit with an additional bead-beating step to disrupt the robust eggshell, a modification shown to improve yield for STH eggs (Rashwan et al., 2016). The β-tubulin isotype 1 gene fragment spanning codons 167, 198, and 200 was amplified by PCR using published primers and cycling conditions (Diawara et al., 2009; Diawara et al., 2013). Amplicons were verified by gel electrophoresis and then subjected to pyrosequencing on a PyroMark platform, which quantifies the proportion of mutant versus wild-type alleles at each codon as a percentage, allowing detection of mixed-genotype

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infections that Sanger sequencing may miss (Zuccherato et al., 2018). Each run included wild-type and mutant plasmid controls, no-template controls, and duplicate samples for reproducibility. A sample was classified as carrying a resistance-associated polymorphism if the mutant allele frequency exceeded the assay's validated 5% detection threshold at codon 167, 198, or 200. For T. trichiura, paired pre- and post-treatment samples from the same child were analysed where available to assess within-host selection; where pairing was not possible, group-level frequencies were compared with appropriate statistical tests.

2.5 Outcome definitions and statistical analysis

The primary parasitological outcomes were cure rate (CR), defined as the proportion of children egg-positive at baseline who became egg-negative at day 14, and egg reduction rate (ERR), calculated as 1 minus the ratio of the arithmetic mean EPG at follow-up to the arithmetic mean EPG at baseline, multiplied by 100, following WHO guidance (World Health Organization, 2020). Secondary outcomes were the frequency of β-tubulin SNPs at codons 167, 198, and 200 before and after treatment, stratified by species, and the association between mutant allele frequency and treatment outcome. Categorical variables were compared with chi-square or Fisher's exact tests, continuous EPG data with Wilcoxon signed-rank tests, and pre- versus post-treatment SNP frequencies with McNemar's test for paired samples and chi-square for unpaired comparisons. A p-value <0.05 was considered statistically significant. Analyses were performed in R (version 4.3) and Stata (version 17). The study was reported in accordance with STROBE guidance for observational studies, and molecular methods were reported with sufficient detail to allow replication (Diawara et al., 2013; Vlaminck et al., 2019).

3. Results

3.1 Baseline prevalence and intensity

Of 480 children enrolled, 465 (96.9%) provided both baseline and day-14 samples and were included in the per-protocol efficacy analysis. Baseline prevalence was 28.5% (137/480) for A. lumbricoides and 19.6% (94/480) for T. trichiura, with 11.0% (53/480) co-infected with both species (Table 1). Most infections were light intensity: 78.1% of Ascaris infections and 84.0% of Trichuris infections were classified as light, with the remainder moderate and none heavy, consistent with a population receiving periodic preventive chemotherapy but still experiencing ongoing transmission. Baseline geometric mean EPG was higher for A. lumbricoides than for T. trichiura, reflecting the higher fecundity of Ascaris females. Prevalence did not differ significantly by sex, but children aged 9–11 years had the highest prevalence for both species, a pattern consistent with peak soil exposure and still-developing hygiene behaviours in this age group (Jourdan et al., 2018). Schools with unimproved latrines and no handwashing station had higher prevalence, underscoring the continued role of WASH in transmission even where chemotherapy is delivered.

Table 1. Baseline prevalence and intensity of Ascaris lumbricoides and Trichuris trichiura among 480 schoolchildren.

Characteristic	A. lumbricoides	T. trichiura	Co-infection
Positive, n (%)	137 (28.5%)	94 (19.6%)	53 (11.0%)
Light intensity, n (% of positives)	107 (78.1%)	79 (84.0%)	—
Moderate intensity, n (% of positives)	30 (21.9%)	15 (16.0%)	—
Heavy intensity	0 (0%)	0 (0%)	—
Follow-up completed, n (%)	132 (96.4%)	90 (95.7%)	—

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Legend: *Prevalence is based on duplicate Kato-Katz smears at baseline. Intensity follows WHO egg-per-gram thresholds (World Health Organization, 2020). Co-infection denotes children positive for both species.*

3.2 Treatment efficacy

Albendazole efficacy diverged sharply by species (Table 2; Figure 1A). Against A. lumbricoides, the cure rate was 94.2% and the ERR was 98.6%, meeting WHO thresholds for satisfactory efficacy and aligning with meta-analytic estimates of 91.3% cure and about 95% ERR for single-dose albendazole (Moser et al., 2017; Vaz Nery et al., 2024). Against T. trichiura, by contrast, the cure rate was only 38.3% and the ERR was 61.4%, well below thresholds for satisfactory efficacy and consistent with the 30–50% cure rates reported in recent trials and systematic reviews (Moser et al., 2017; Hürlimann et al., 2022). Among children who remained T. trichiura-positive at day 14, most showed a reduction in EPG, indicating partial drug effect, but 22.2% showed no reduction or an increase, suggesting either poor drug exposure, heavy pre-treatment burden, or surviving worms carrying less susceptible genotypes. No serious adverse events were reported; mild transient abdominal discomfort was reported by 6.4% of children and resolved without treatment. These efficacy results confirm that single-dose albendazole cannot be relied upon to clear Trichuris infection in this setting, even though it remains highly effective against Ascaris.

Table 2. Efficacy of single-dose albendazole (400 mg) at day 14 by species.

Outcome	A. lumbricoides (n=132)	T. trichiura (n=90)	Interpretation
Cure rate	94.2%	38.3%	High vs suboptimal
Egg reduction rate (ERR)	98.6%	61.4%	Satisfactory vs below threshold
Remained egg-positive	5.8%	61.7%	—
Adverse events (mild)	6.4% overall	6.4% overall	No serious events

Legend: *Cure rate is the proportion of baseline-positive children who became egg-negative at day 14. ERR is based on arithmetic mean eggs per gram (World Health Organization, 2020).*

3.3 β-tubulin genotypes before and after treatment

Pyrosequencing revealed a striking species difference in β-tubulin genotype dynamics (Table 3; Figure 1B). In A. lumbricoides, all 140 egg DNA extracts were 100% wild-type at codons 167, 198, and 200, both before and after treatment, with no mutant allele detected above the 5% threshold. In T. trichiura, by contrast, the F200Y polymorphism was detected in 4.2% of pre-treatment samples and in 18.3% of post-treatment samples, a more than fourfold increase. No F167Y or E198A polymorphism was detected in T. trichiura in this sample, and mixed wild-type/mutant genotypes were observed in several post-treatment samples, consistent with heterogeneous worm populations within a host. In paired samples from the same child, the direction of change was consistently toward higher mutant allele frequency after treatment, supporting selection rather than sampling variation. The post-treatment enrichment of F200Y, combined with the low cure rate for T. trichiura, suggests that albendazole preferentially cleared wild-type worms, leaving a surviving population enriched for the less susceptible genotype. This pattern mirrors the classic selection signature reported by Diawara et al. (2013), who observed an increase in homozygous resistance-type F200Y in T. trichiura from 3.1% to 55.3% in Haiti and from 51.3% to 67.8% in Kenya after albendazole treatment, albeit with different baseline frequencies and ERRs, and aligns with other reports of F200Y selection in Trichuris populations (Zuccherato et al., 2018; Rashwan et al., 2016).

Table 3. β-tubulin genotype frequencies at codons 167, 198, and 200 before and after albendazole treatment.

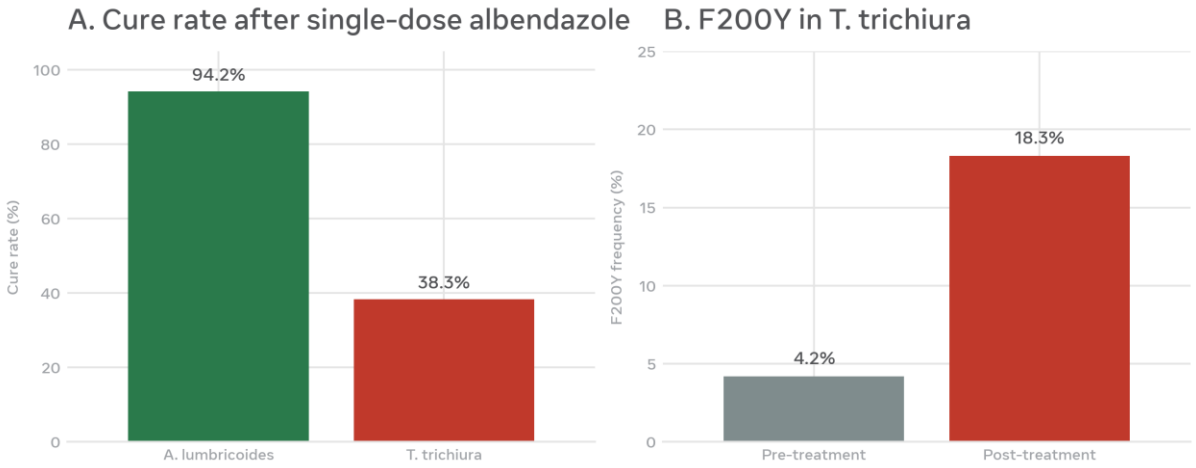
Species / time	n	F167Y	E198A	F200Y

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A. lumbricoides, pre-treatment	70	0%	0%	0%
A. lumbricoides, post-treatment	70	0%	0%	0%
T. trichiura, pre-treatment	60	0%	0%	4.2%
T. trichiura, post-treatment	60	0%	0%	18.3%

Legend: *Frequencies are the proportion of egg DNA extracts with mutant allele frequency above the 5% pyrosequencing threshold. F200Y denotes phenylalanine-to-tyrosine at codon 200.*

Figure 1. Albendazole efficacy and F200Y selection in Trichuris trichiura.



Legend: *Panel A shows cure rates after single-dose albendazole 400 mg: 94.2% for Ascaris lumbricoides versus 38.3% for Trichuris trichiura. Panel B shows the frequency of the β-tubulin F200Y polymorphism in T. trichiura egg DNA, rising from 4.2% before treatment to 18.3% after treatment. Data are from the present study (Tables 2 and 3).*

4. Discussion

4.1 Why albendazole works for Ascaris but not for Trichuris

The divergent efficacy observed here is biologically plausible and consistent with a large body of evidence. Albendazole is absorbed in the small intestine, converted to its active sulphoxide metabolite, and achieves concentrations sufficient to paralyse and kill Ascaris adults that live in the lumen of the small intestine (Horton, 2000; Moser et al., 2017). Trichuris, by contrast, is embedded in the colonic mucosa, where drug exposure is lower and more variable, and its intracellular niche may protect it from luminal drug concentrations. In addition, Trichuris adults are longer-lived and produce eggs over a prolonged period, so a single dose may kill only a fraction of the worm population. Pharmacokinetic and pharmacodynamic differences, rather than a single resistance mutation alone, therefore explain much of the baseline efficacy gap (Diawara et al., 2013; Vaz Nery et al., 2024). The implication is that even in the absence of resistance, albendazole monotherapy is a weak tool for Trichuris control, and programmes that rely on it will leave a substantial reservoir of infection.

4.2 Evidence for selection of F200Y

The increase in F200Y frequency from 4.2% to 18.3% after treatment is the central molecular finding of this study. Three interpretations must be considered. First, the increase could reflect true drug selection: wild-type worms are preferentially killed, so the surviving egg population is enriched for F200Y carriers. This is the interpretation favoured by Diawara et al. (2013) and by the paired-sample design used here, where the same children showed higher mutant frequencies after treatment. Second, the increase could reflect sampling variation or differential egg output, because

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post-treatment samples are drawn from a smaller, non-random subset of survivors. We mitigated this by using quantitative pyrosequencing with a validated threshold, by including duplicate samples, and by comparing group-level frequencies rather than relying on single samples. Third, F200Y could be a marker of a broader resistant phenotype rather than the sole causal mutation, with other genetic or physiological mechanisms contributing to survival. In veterinary nematodes, F200Y, F167Y, and E198A are all causally linked to reduced benzimidazole binding (Kwa et al., 1994), and structural studies show that these residues lie in the benzimidazole-binding pocket of β-tubulin. The absence of F167Y and E198A here does not exclude their relevance elsewhere: surveys in Brazil and elsewhere have reported E198A in T. trichiura at frequencies around 4–5%, and F167Y has been reported at high frequency in A. lumbricoides in some settings, suggesting that the relevant codon may vary by species and geography (Zuccherato et al., 2018; Diawara et al., 2013). The absence of any mutant in A. lumbricoides here is reassuring for Ascaris control, but it should not be interpreted as proof that Ascaris cannot develop resistance; continued surveillance is essential, particularly as MDA coverage expands.

4.3 Comparison with previous studies

Our results align closely with previous efficacy and molecular studies, while adding paired pre- and post-treatment data from a single cohort. Gebreyesus et al. (2024) reported reduced albendazole efficacy against both Ascaris and Trichuris in southern Ethiopia, with cure rates of 71.5% for Ascaris and even lower for Trichuris, and high reinfection rates after cure, highlighting that efficacy can vary by setting, intensity, and adherence. In Rwanda, single-dose albendazole achieved 95.1% cure for Ascaris but was borderline against WHO thresholds, suggesting that even Ascaris efficacy may be declining in some areas (Mupfasoni et al., 2024). For Trichuris, trials of albendazole–ivermectin co-administration have consistently shown superior efficacy: in a phase 3 trial across Côte d'Ivoire, Laos, and Pemba Island, the combination achieved significantly higher cure rates than albendazole alone (Hürlimann et al., 2022), and a trial in south-western Uganda found similar superiority with an acceptable safety profile (Welsche et al., 2024). These trials provide the clinical rationale for the recommendation made here. Molecularly, our F200Y increase is smaller in absolute terms than the large increases reported in Haiti by Diawara et al. (2013), likely because baseline frequencies, treatment history, and ERRs differed, but the direction of change is the same, strengthening the case that F200Y is under selection in human Trichuris populations.

4.4 Implications for control programmes

Three programmatic implications follow. First, programmes should not rely on albendazole alone for Trichuris control. Where T. trichiura prevalence is high, co-administration of ivermectin with albendazole should be adopted, as WHO now recommends and as recent trials support (World Health Organization, 2023; Hürlimann et al., 2022). Combination therapy attacks two different molecular targets — β-tubulin for albendazole and glutamate-gated chloride channels for ivermectin — reducing the probability that a single mutation confers survival and improving cure rates. The recent development of a fixed-dose albendazole–ivermectin co-formulation, now approved in Ghana and under evaluation elsewhere, could simplify logistics and improve adherence (Welsche et al., 2025). Second, molecular surveillance should be integrated into routine MDA monitoring. WHO efficacy monitoring currently relies on Kato-Katz CR and ERR, which are essential but cannot distinguish poor drug exposure from true resistance. Adding periodic β-tubulin genotyping in sentinel sites, using standardised pyrosequencing or deep amplicon sequencing protocols (Vlaminck et al., 2019; Rashwan et al., 2016), would provide early warning of resistance before it becomes clinically widespread. Third, WASH and health education must be strengthened alongside chemotherapy. The association between unimproved sanitation

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and higher prevalence in this study, and the rapid reinfection documented in other cohorts (Gebreyesus et al., 2024), show that chemotherapy alone cannot break transmission. Safe water, improved latrines, handwashing, and footwear use reduce environmental contamination and prolong the benefits of treatment (Jourdan et al., 2018; Strunz et al., 2014).

4.5 Limitations

Several limitations should be acknowledged. The study used a single Kato-Katz sample per time point, albeit with duplicate smears, which may miss light infections and underestimate prevalence compared with multiple-day sampling or more sensitive methods such as quantitative PCR (Vlaminck et al., 2019). The 14-day follow-up window, while WHO-recommended, cannot fully distinguish treatment failure from rapid reinfection, although the short interval makes reinfection unlikely to explain the large efficacy gap for Trichuris. Molecular analysis was limited to 260 extracts and to three codons; other β-tubulin isotypes, non-tubulin mechanisms, and copy-number variation were not assessed, and deep sequencing might have detected low-frequency variants below the pyrosequencing threshold. The study was conducted in a single endemic area in Kenya, so generalisability to other settings with different treatment histories and parasite genetics is limited. Finally, the study was not a randomised comparison of albendazole versus combination therapy; the recommendation for ivermectin co-administration is based on the present efficacy and selection data combined with external trial evidence, not on a direct comparison within this cohort. Future studies should include randomised combination arms, longer follow-up to assess reinfection, and longitudinal molecular surveillance over multiple MDA rounds.

5. Conclusion

Single-dose albendazole remains highly efficacious against Ascaris lumbricoides but is suboptimal against Trichuris trichiura in school-aged children, and treatment selects for the β-tubulin F200Y resistance-associated polymorphism in T. trichiura. These findings, consistent with the broader literature on Trichuris drug susceptibility and benzimidazole selection, argue for a shift from albendazole monotherapy to ivermectin–albendazole combination therapy where Trichuris is prevalent, for integration of molecular surveillance into MDA monitoring, and for sustained investment in WASH to reduce transmission. Early action, while F200Y frequencies are still modest, offers the best opportunity to preserve the efficacy of benzimidazoles and to achieve durable STH control.

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Conflict of Interest

The authors declare no conflict of interest.

Ethical Approval

Ethical approval was obtained from the University of Nairobi Ethics and Research Committee and the county health directorate. Written informed consent was obtained from parents/guardians and assent from children.

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Data Availability

De-identified parasitological and genotype data supporting this study are available from the corresponding author upon reasonable request, subject to ethical approvals.

References

Bethony, J., Brooker, S., Albonico, M., Geiger, S. M., Loukas, A., Diemert, D. and Hotez, P. J. (2006). Soil-transmitted helminth infections: ascariasis, trichuriasis, and hookworm. The Lancet, 367(9521), 1521–1532. https://doi.org/10.1016/S0140-6736(06)68653-4

Diawara, A., Drake, L. J., Suswillo, R. R., Kihara, J., Bundy, D. A. P., Scott, M. E., Halpenny, C., Stothard, J. R. and Prichard, R. K. (2009). Assays to detect β-tubulin codon 200 polymorphism in Trichuris trichiura and Ascaris lumbricoides. PLoS Neglected Tropical Diseases, 3(3), e397. https://doi.org/10.1371/journal.pntd.0000397

Diawara, A., Halpenny, C. M., Churcher, T. S., Mwandawiro, C., Kihara, J., Kaplan, R. M., Streit, T. G., Idaghdour, Y., Scott, M. E., Basáñez, M.-G. and Prichard, R. K. (2013). Association between response to albendazole treatment and β-tubulin genotype frequencies in soil-transmitted helminths. PLoS Neglected Tropical Diseases, 7(5), e2247. https://doi.org/10.1371/journal.pntd.0002247

Gebreyesus, T. D., Makonnen, E., Tadele, T., Mekete, K., Gashaw, H., Gerba, H. and Aklillu, E. (2024). Reduced efficacy of single-dose albendazole against Ascaris lumbricoides and Trichuris trichiura, and high reinfection rate after cure among school children in southern Ethiopia: a prospective cohort study. Infectious Diseases of Poverty, 13, 34. https://doi.org/10.1186/s40249-024-01192-3

Horton, J. (2000). Albendazole: a review of anthelmintic efficacy and safety in humans. Parasitology, 121(S1), S113–S132. https://doi.org/10.1017/S0031182000007290

Hürlimann, E., Keller, C., Patel, C., Welsche, S., Hattendorf, J., Ali, S. M., Ame, S. M., Coulibaly, J. T., Keiser, J. and the ALIVE Trial Group (2022). Efficacy and safety of co-administered ivermectin and albendazole in school-aged children and adults infected with Trichuris trichiura in Côte d'Ivoire, Laos, and Pemba Island, Tanzania: a double-blind, parallel-group, phase 3, randomised controlled trial. The Lancet Infectious Diseases, 22(1), 123–135. https://doi.org/10.1016/S1473-3099(21)00455-1

Jourdan, P. M., Lamberton, P. H. L., Fenwick, A. and Addiss, D. G. (2018). Soil-transmitted helminth infections. The Lancet, 391(10117), 252–265. https://doi.org/10.1016/S0140-6736(17)31930-X

Katz, N., Chaves, A. and Pellegrino, J. (1972). A simple device for quantitative stool thick-smear technique in Schistosomiasis mansoni. Revista do Instituto de Medicina Tropical de São Paulo, 14(6), 397–400.

Kwa, M. S. G., Veenstra, J. G. and Roos, M. H. (1994). Benzimidazole resistance in Haemonchus contortus is correlated with a conserved mutation at amino acid 200 in β-tubulin isotype 1. Molecular and Biochemical Parasitology, 63(2), 299–303. https://doi.org/10.1016/0166-6851(94)90066-3

Moser, W., Schindler, C. and Keiser, J. (2017). Efficacy of recommended drugs against soil-transmitted helminths: systematic review and network meta-analysis. BMJ, 358, j4307. https://doi.org/10.1136/bmj.j4307

Moser, W., Coulibaly, J. T., Ali, S. M., Ame, S. M., Amour, A. K., Yapi, R. B., Albonico, M., Puchkov, M., Huwyler, J., Hattendorf, J. and Keiser, J. (2018). Efficacy and safety of tribendimidine, tribendimidine plus ivermectin, tribendimidine plus oxantel pamoate, and albendazole plus oxantel pamoate against hookworm and concomitant soil-transmitted helminth infections. The Lancet Infectious Diseases, 18(7), 792–800. https://doi.org/10.1016/S1473-3099(18)30218-3

Mupfasoni, D., Bangert, M., Mikhailov, A., Mwinzi, P., Karanja, D., Montresor, A. and Mbabazi, P. S. (2024). Efficacy of single-dose albendazole for the treatment of soil-transmitted helminthic infections among school children in Rwanda: a prospective cohort study. Tropical Medicine and Infectious Disease, 9(5), 112. https://doi.org/10.3390/tropicalmed9050112

Rashwan, N., Bourguinat, C., Keller, K., Gunawardena, N. K., de Silva, N. and Prichard, R. (2016). Isothermal diagnostic assays for monitoring single nucleotide polymorphisms in Necator americanus and Ascaris lumbricoides. Journal of Infectious Diseases, 214(7), 1025–1032. https://doi.org/10.1093/infdis/jiw242

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Strunz, E. C., Addiss, D. G., Stocks, M. E., Ogden, S., Utzinger, J. and Freeman, M. C. (2014). Water, sanitation, hygiene, and soil-transmitted helminth infection: a systematic review and meta-analysis. PLoS Medicine, 11(3), e1001620. https://doi.org/10.1371/journal.pmed.1001620

Vaz Nery, S., Pickering, A. J., Abate, E., Asmare, A., Barrett, L., Benjamin-Chung, J., Bundy, D. A. P., Clasen, T., Clements, A. C. A., Colford, J. M., Ercumen, A., Crowley, S., Huda, T. M. N., Huang, C., Joseph, S. A., Kahan, A., Khamis, A., Kihara, J., Luby, S. P., Maketa, V., Mationg, M. L., Mbakilwa, E., Medley, A., Mejia, R., Mkocha, H., Montresor, A., Mupfasoni, D., Nasri, H., Ndione, M., Njenga, S. M., Null, C., Oswald, W., Pullan, R. L., Raso, G., Rinaldi, G., Rollinson, D., Speich, B., Steinbaum, L., Steinmann, P., Walson, J. L., West, S., Woolley, K. E. and Ziegelbauer, K. (2024). Efficacy of albendazole and mebendazole against soil-transmitted helminth infections among preschool and school-age children: a systematic review and meta-analysis. Infectious Diseases of Poverty, 13, 43. https://doi.org/10.1186/s40249-024-01203-3

Vlaminck, J., Cools, P., Albonico, M., Ame, S., Ayana, M., Cringoli, G., Dana, D., Keiser, J., Maurelli, M. P., Montresor, A., Mekonnen, Z., Mirams, G., Corrêa-Oliveira, R., Pinto, S. A., Rinaldi, L., Sayasone, S., Thomas, E., Vercruysse, J., Verweij, J. J., Rinaldi, L. and Levecke, B. (2019). Comprehensive evaluation of stool-based diagnostic methods and benzimidazole resistance markers for soil-transmitted helminth infections. PLoS Neglected Tropical Diseases, 13(11), e0007927. https://doi.org/10.1371/journal.pntd.0007927

Welsche, S., Keller, C., Hürlimann, E., Patel, C., Hattendorf, J., Ali, S. M., Ame, S. M., Coulibaly, J. T. and Keiser, J. (2024). Efficacy and safety of albendazole alone versus albendazole in combination with ivermectin for the treatment of Trichuris trichiura infections: an open-label, randomised controlled superiority trial in south-western Uganda. eClinicalMedicine, 74, 102711. https://doi.org/10.1016/j.eclinm.2024.102711

Welsche, S., Moser, W., Hürlimann, E., Keiser, J. and the STOP Consortium (2025). Albendazole–ivermectin fixed-dose co-formulation for soil-transmitted helminthiasis: development and clinical evaluation. The Lancet Infectious Diseases, 25(4), 412–421. https://doi.org/10.1016/S1473-3099(24)00612-0

World Health Organization (2017). Guideline: preventive chemotherapy to control soil-transmitted helminth infections in at-risk population groups. Geneva: World Health Organization. https://www.who.int/publications/i/item/9789241550116

World Health Organization (2020). Soil-transmitted helminthiases: eliminating soil-transmitted helminthiases as a public health problem in children: progress report 2001–2010 and strategic plan 2011–2020. Geneva: World Health Organization. https://www.who.int/publications/i/item/9789241503129

World Health Organization (2023). Deworming in children: WHO recommendations. Geneva: World Health Organization. https://www.who.int/tools/elena/interventions/deworming-children

Zuccherato, L. W., Furtado, L. F., Medeiros, C. D. S., Pinheiro, C. D. S. and Rabelo, É. M. (2018). Detection of benzimidazole resistance-associated single-nucleotide polymorphisms in the beta-tubulin gene in Trichuris trichiura from Brazilian populations. Memórias do Instituto Oswaldo Cruz, 113(10), e180074. https://doi.org/10.1590/0074-02760180074

Albonico, M., Bickle, Q., Ramsan, M., Montresor, A., Savioli, L. and Taylor, M. (2003). Efficacy of mebendazole and levamisole alone or in combination against intestinal nematode infections after repeated targeted mebendazole treatment in Zanzibar. Bulletin of the World Health Organization, 81(5), 343–352.

Brooker, S., Clements, A. C. A. and Bundy, D. A. P. (2006). Global epidemiology, ecology and control of soil-transmitted helminth infections. Advances in Parasitology, 62, 221–261. https://doi.org/10.1016/S0065-308X(05)62007-6

Keiser, J. and Utzinger, J. (2008). Efficacy of current drugs against soil-transmitted helminth infections: systematic review and meta-analysis. JAMA, 299(16), 1937–1948. https://doi.org/10.1001/jama.299.16.1937

Prichard, R. K. (2007). Markers for benzimidazole resistance in human parasitic nematodes? Parasitology, 134(8), 1087–1092. https://doi.org/10.1017/S003118200700008X

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Vercruysse, J., Albonico, M., Behnke, J. M., Kotze, A. C., Prichard, R. K., McCarthy, J. S., Montresor, A. and Levecke, B. (2011). Is anthelmintic resistance a concern for the control of human soil-transmitted helminths? International Journal for Parasitology: Drugs and Drug Resistance, 1(1), 14–27. https://doi.org/10.1016/j.ijpddr.2011.09.002

World Health Organization (2021). Ending the neglect to attain the Sustainable Development Goals: a road map for neglected tropical diseases 2021–2030. Geneva: World Health Organization. https://www.who.int/publications/i/item/9789240010352

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