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Antiamoebic Properties of the Actinomycete Metabolites Echinomycin A and Tirandamycin A

Avelina Espinosa
Roger Williams University, aespinosa@rwu.edu

Aaron M. Socha
University of Rhode Island

Erica Ryke
Roger Williams University

David C. Rowley
University of Rhode Island

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SHORT COMMUNICATION

Antiamoebic properties of the actinomycete metabolites echinomycin A and tirandamycin A

Avelina Espinosa · Aaron M. Socha · Erica Ryke · David C. Rowley

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Abstract *Entamoeba histolytica* infects 50 million people per year, causing 100,000 deaths worldwide. The primary treatment for amoebiasis is metronidazole. However, increased pathogen resistance combined with the drug's toxic side effects encourages a search for alternative therapeutic agents. Secondary metabolites from marine bacteria are a promising resource for antiprotozoan drug discovery. In this study, extracts from a collection of marine-derived actinomycetes were screened for antiamoebic properties, and the activities of antibiotics echinomycin A and tirandamycin A are shown. Both antibiotics inhibited the in vitro growth of a *E. histolytica* laboratory strain (HM-1:IMSS) and a clinical isolate (Colombia, Col) at 30- to 60-μM concentrations. EIC_{50} (estimated inhibitory concentration) values were comparable for both antibiotics (44.3–46.3 μM) against the *E. histolytica* clinical isolate.

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A. Espinosa (✉) · E. Ryke
Department of Biology, Roger Williams University,
One Old Ferry Road,
Bristol, RI 02809, USA
e-mail: aespinosa@rwu.edu

A. M. Socha · D. C. Rowley
Department of Biomedical and Pharmaceutical Sciences,
College of Pharmacy, University of Rhode Island,
Kingston, RI 02881, USA

Present Address:
A. M. Socha
Department of Chemistry and Chemical Technology,
Bronx Community College,
Bronx, NY 10453, USA

Introduction

Entamoeba histolytica, the causative agent of amoebic dysentery, is a parasitic contaminant of food, water, and soil. Upon colonizing the intestine of a primate host, *Entamoeba* cysts metamorphose into disease-causing trophozoites. The parasite infects 12 % of the world's population. Annually, 50 million patients require clinical treatment, and up to 100,000 cases result in mortality (Walsh 1986; Stanley 2003; Haque et al. 2003; Cotruvo et al. 2004, Ximénez et al. 2009). Approximately 90 % of patients with mild to moderate amoebic symptoms can be treated with metronidazole or other nitroimidazole derivatives. Currently, luminal amebicides (e.g., diloxanide furoate) are effective on intestinal lumen trophozoites but not capable to reach tissue ameba (Pritt and Clark 2008; Kenny and Kelly 2009); tissue amebicides (e.g., metronidazole, dehydroemetine, chloroquine, and nitazoxanide) are effective in the treatment of invasive amebiasis but not able to control luminal trophozoites (Pritt and Clark 2008; Kenny and Kelly 2009). Close to 90 % of patients with mild to moderate amoebic symptoms respond to metronidazole and other nitroimidazole derivatives. Because of misdiagnoses and asymptomatic carriers (host nonpathogenic *Entamoeba dispar* instead of the infective *E. histolytica*) in resource-limited countries, overtreatment with both drugs is common (Pritt and Clark 2008). No clinical reports exist on *E. histolytica* resistance to metronidazole; however, in vitro metronidazole-resistant *E. histolytica* strains have been selected (Wassmann et al. 1999). Resistance in hospital strains of *Trichomonas vaginalis*, *Giardia lamblia*, as well as in anaerobic bacteria (i.e., *Clostridium* sp. and *Bacillus fragilis*) has been reported (Bendesky et al. 2002; Crowell et al. 2003; Ali and Nozaki 2007). Although some toxic side effects, neurological, reproductive, and potential carcinogenic concerns have been reported for metronidazole and its derivatives (Bendesky et al. 2002), the strongest rationale for the search/design of novel

antiamebic compounds is a drug that manages both invasive and luminal amebiasis. Anaerobic pathogens have evolved adaptive metabolic enzymes that differ from vertebrates, which could be ideal targets of novel drug discovery and design (Ali and Nozaki 2007).

Secondary metabolites produced by actinobacteria have guided the development of numerous clinically used antimicrobial agents (Bérdy 2005). Interestingly, the parent compound of metronidazole, the nitroimidazole azomycin, was isolated from *Streptomyces eurocidicus* in the 1950s (Osato et al. 1955). In addition to their effectiveness as antibacterial agents, actinomycete metabolites have recently attracted attention as antiparasitic agents. A screening study of 400 compounds isolated from soil-dwelling microbes revealed the potent and selective antitrypanosomal activity of ten structurally diverse metabolites (Otoguro et al. 2008). Salinosporamide A, produced by the marine actinomycete *Salinispora tropica*, strongly inhibits erythrocytic stages of the of the human malaria parasite *Plasmodium falciparum,* perhaps through interactions with the 20S proteasome (Prudhomme et al. 2008).

Protistan grazing poses a significant environmental pressure on marine bacterial communities, and recent evidence supports that actinobacteria may not be as susceptible to protists' attack as other types of bacteria (Fenical and Jensen 2006). Chemical defenses may be partly responsible for these findings. For example, the bacterial metabolite violacein has been shown to reduce protozoan grazing (Matz et al. 2004). These findings suggest that new antiamoebic compounds can be identified from increased investigations of microbial metabolites. In a search for such agents, we recently undertook a screening of chemical extracts derived from fermentations of actinomycetes isolated from marine coastal sediments. Herein, we report the isolation and purification of two antibiotics, echinomycin A and tirandamycin A, and their inhibitory effect on of *E. histolytica* trophozoites in vitro.

Materials and methods

All reagents and solvents were purchased from Fisher Scientific and were of analytical grade. UV spectra were recorded on a DU 800 spectrophotometer (Beckman-Coulter), and IR spectra were acquired on a Nexus 470 FT-IR (Thermo Nicolet). NMR spectra were recorded on a Bruker Biospin spectrometer (400 MHz for ^{1}H, 100 MHz for ^{13}C) and were referenced to residual solvent signals with resonances at $^{1}H/^{13}C = \delta\ 7.24/77.0$ ($CDCl_3$). Electrospray ionization mass spectrometry was accomplished in 50:50 acetonitrile/water (+0.1 % formic acid) on a Mariner© mass spectrometer (Applied Biosystems). High-performance liquid chromatography (HPLC) was performed using a Waters 600 pump and a 486 tunable absorbance detector using a Waters X-Terra® Prep RP18 column (5 mm 19×100 mm).

Marine actinomycete strain collection, cultivation, and biological screening

A library of marine actinomycetes was isolated from marine sediments collected in Fisher's Island Sound, NY. Individual strains were isolated using heat shock and desiccation methods to select for Gram-positive bacteria (Ceri et al. 1999; LaPlante and Rybak 2004; Thelaus et al. 2008). Pure colonies were isolated on YP marine agar (1 g yeast extract, 5 g peptone, 15 g agar per 1 L of synthetic sea water (Instant Ocean; 36 g/L)) supplemented with cycloheximide to suppress fungal growth. A total of 55 isolates that morphologically resembled *Streptomyces* and *Micromonospora* spp. were individually cultured in 1 L of yeast-peptone marine media. After approximately 5–8 days of growth, cells were removed by filtration over Celite, and culture broths were extracted with 500 mL ethyl acetate. The resulting extracts were stored in dimethyl sulfoxide (DMSO) at −20 °C and tested for inhibition of amoebic growth (Espinosa et al. 2001, 2004, 2009) against *E. histolytica* HM-1:1MSS (standard strain; Espinosa et al. 2001, 2004, 2009) and *E. histolytica* Col [clinical isolate from a Colombian patient, obtained from New York University (NYU), Dan Eichinger Laboratory]. The extracts of two *Streptomyces* strains, isolates URI-F11 and URI-F39, showed inhibitory activity in an in vitro trophozoite growth assay, and were selected for further chemical investigation. Strain URI-F11 was isolated from a marine sediment sample collected from a depth of 12 m in Fisher's Island Sound, NY (41°17′00″ N, 72° 2′11″ W) and identified as a *Streptomyces* sp. by 16S rRNA sequence comparison (deposited with GenBank as accession no. JF939719, Socha et al. 2007). *Streptomycete* strain URI-F39 strain was isolated and identified as previously described (Socha et al. 2009).

Purification and structure identification of tirandamycin A and echinomycin A antibiotics

Strain URI-F11 was cultivated in 16 1-L cultures for 7 days at 155 RPM and 24°C in YP marine broth. The cells were removed by cheesecloth filtration, and the broth was partitioned between ethyl acetate and H_2O. The organic layer was concentrated in vacuo to yield 800 mg. The extract was separated by flash chromatography using a 20–100 % gradient of methanol in H_2O (HP-20-SS Diaion® resin, Supelco). Reversed-phase HPLC of the 80 % methanol fraction using 50–100 % acetonitrile in H_2O yielded tirandamycin A (9.6 mg).

Tirandamycin was characterized by ^{1}H and ^{13}C NMR spectral comparison to the literature values (MacKellar et

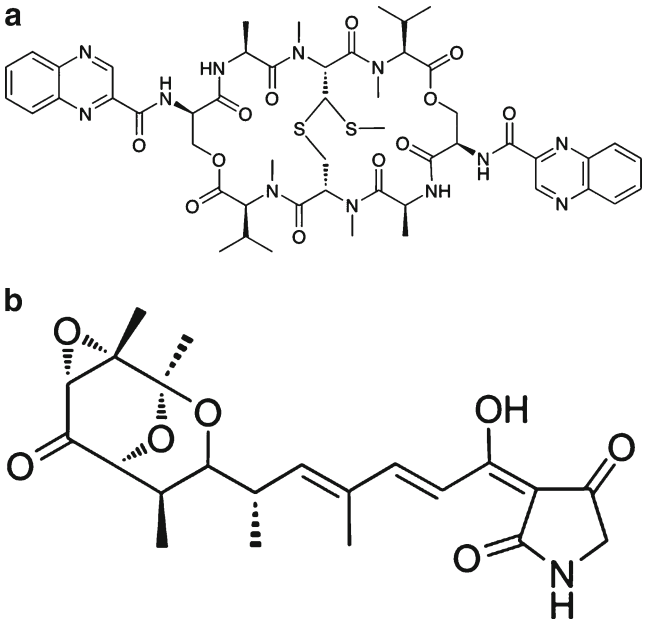

Fig. 1 Chemical structures of **a** echinomycin A and **b** tirandamycin A

al. 1971). The UV and IR spectra were also identical to the published values (Meyer 1971; Lee and Rinehart 1980). A molecular weight of 418.2 [M+H]+124 confirmed the structure. Echinomycin A was isolated from URI F39 strain as previously described (The NMR spectra for tirandamycin A and echinomycin A corroborated their chemical composition, Electronic supplementary material Fig S1, Socha et al. 2009).

In vitro inhibitory assay

Trophozoites from *E. histolytica* HM-1:IMSS and *E. histolytica* Colombia (Col), isolated from a Colombian patient) were cultured under axenic conditions in flat-bottomed 48-well plates containing 1.4 ml of Diamond's TYI-S-33 medium as previously described (Espinosa et al. 2001, 2004, 2009). Trophozoites in log phase were used in all experiments. Growth counts were averaged from three replicate wells and three separate experiments. Amoebic cultures were closely examined to verify absence of bacterial contamination in tubes. To determine inhibition of *E. histolytica* growth, standard culture tubes containing an initial inoculation of 5×10^3 trophozoites were grown for 48 and 72 h in TYI-S-33 (alone) or supplemented with 30 μM echinomycin A, 30 μM tirandamycin A, 60 μM echinomycin A, or 60 μM tirandamycin A, and counted using a hemocytometer. Metronidazole at a concentration of 20 μM was used as positive control of inhibition (Espinosa et al. 2001, 2004, 2009). All test compounds were dissolved in DMSO; a similar volume of DMSO was added to control wells of ameba (data not shown) to discard toxicity due to the solvent.

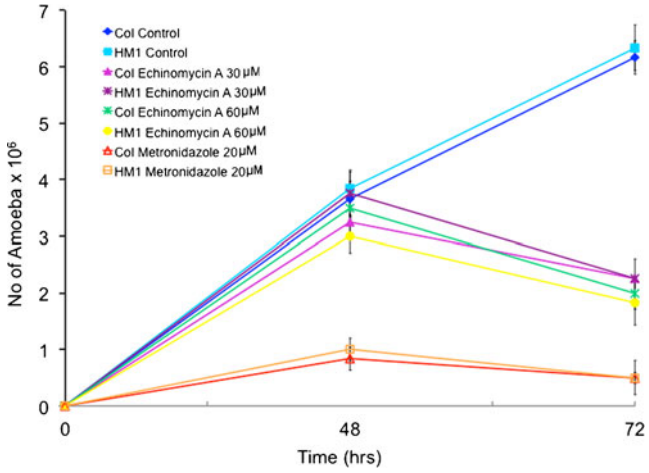

Fig. 2 Echinomycin A inhibits *E. histolytica* HM-1:1MSS and Col trophozoite growth. An initial 5×10^3 HM-1:1MSS and Col *E. histolytica* trophozoites were inoculated per tube with TYI-S-33 media alone (control) and plus inhibitor (echinomycin A or metronidazole) and incubated at 37 °C for 48 to 72 h

Results

The growth inhibitory properties of pure echinomycin A (Fig. 1a) and tirandamycin A (Fig. 1b) were measured against *E. histolytica* HM-1:IMSS (Espinosa et al. 2001, 2004, 2009) and *E. histolytica* Col. The latter is a clinical isolate derived from a Colombian patient (obtained from NYU, Dan Eichinger Laboratory). Each compound inhibited the growth of both *E. histolytica* strains at 30- and 60-μM concentrations (Figs. 2 and 3). A 60-μM concentration of echinomycin A inhibited 71.1 and 67.6 % of trophozoites, respectively (Fig. 2, Table 1). A 60-μM treatment with tirandamycin A resulted in a slightly stronger

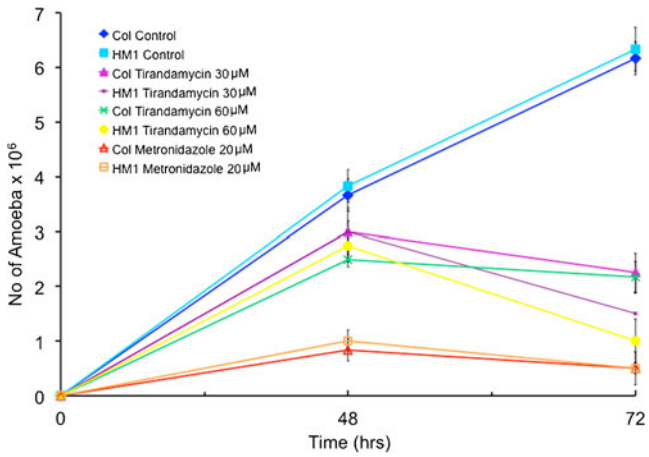

Fig. 3 Tirandamycin A inhibits *E. histolytica* HM-1:1MSS and Col trophozoite growth. An initial 5×10^3 HM-1:1MSS and Col *E. histolytica* trophozoites were inoculated per tube with TYI-S-33 media alone (control) and plus inhibitor (tirandamycin A or metronidazole) and incubated at 37 °C for 48 to 72 h

Table 1 Effect of echinomycin A and tirandamycin on the growth of *E. histolytica* trophozoites (EIC_{50} values for 48 and 72 h are also shown)

Concentration	No. of trophozoites × 10^6 (% inhibition in respect to controls)					
	Echinomycin A		Tirandamycin		Metronidazole	
	48 h	72 h	48 h	72 h	48 h	72 h
E. histolytica HM1:1MSS control	3.83 (NA)	6.33 (NA)	3.83 (NA)	6.33 (NA)	3.83 (NA)	6.33 (NA)
E. histolytica Col control	3.67 (NA)	6.17 (NA)	3.67 (NA)	6.17 (NA)	3.67 (NA)	6.17 (NA)
E. histolytica HM1:1MSS 35.6 μM[a]	–	–	–	3.09 (50)[b]	–	–
E. histolytica Col 46.3 μM[a]	–	–	–	3.16 (50)[b]	–	–
E. histolytica HM1:1MSS 42.2 μM[a]	–	3.09 (50)[b]	–	–	–	–
E. histolytica Col 44.3 μM[a]	–	3.16 (50)[b]	–	–	–	–
E. histolytica HM1:1MSS 50 μM	3.75 (2.1)	2.25 (64.5)	3.0 (21.7)	1.5 (76.3)	ND	ND
E. histolytica Col 50 μM	3.25 (11.4)	2.25 (63.5)	3.0 (18.3)	2.25 (63.5)	ND	ND
E. histolytica HM1:1MSS 60 μM	3.0 (21.7)	1.83 (71.1)	2.75 (28.2)	1.0 (84.2)	ND	ND
E. histolytica Col 60 μM	3.5 (4.6)	2 (67.6)	2.50 (31.9)	2.17 (64.8)	ND	ND
E. histolytica HM1:1MSS 20 μM	ND	ND	ND	ND	1.0 (73.9)	0.5 (92.1)
E. histolytica Col 20 μM	ND	ND	ND	ND	0.83 (77.4)	0.5 (91.9)

NA not applicable

[a] EIC_{50}, estimated inhibitory concentrations of antibiotics required to inhibit 50 % amoebic growth

[b] Estimated no. of trophozoites × 10^6 killed by EIC_{50}

inhibition, demonstrating a 84.2 % reduction in growth of *E. histolytica* HM-1:IMSS and 64.8 % reduction in growth by *E. histolytica* Col (Fig. 3, Table 1). EIC_{50} values were comparable for both antibiotics (44.3–46.3 μM) against *E. histolytica* Col (Table 1). EIC_{50} is defined as the estimated inhibitory concentrations of drug required to inhibit 50 % amoebic growth.

Discussion

Secondary metabolites produced by marine actinomycetes represent a promising resource for antiparasitic drug discovery (Bérdy, 2005; Fenical and Jensen 2006; Otoguro et al. 2008; Prudhomme et al. 2008). This is the first investigation of actinomycete metabolites in the context of amoebic infections. An intial testing of extracts from a panel of 55 marine actinomycetes revealed the antiamoebic activity of echinomycin A and tirandamycin A against *E. histolytica*.

Echinomycin A is a potent antitumor and antibacterial agent that exerts its activity via DNA bisintercalation (Waring and Wakelin 1974). As such, echinomycin A has been shown to inhibit vertebrate DNA replication, chromatin decondensation, and transcription (May et al. 2004). The antiamoebic activity of echinomycin A could be due to the fact that amoeba are highly metabolic cells, which replicate two to three times per day (Ong and Wolfson, 1970; Austin and Warren 1983). Echinomycin has been tested in mice against methicillin-resistant *Staphylococcus aureus* peritoneal infections and shown an ED_{50} of 0.5–1.3 mg/kg with little toxicity (Park et al. 2008).

Tirandamycin A inhibits chain initiation and elongation of bacterial RNA polymerase without acting on mammalian polymerases (Reusser 1976). Three tirandamycins isolated from *Streptomyces* sp. 17944 inhibited the parasitic nematode *Brugia malayi* at 30-μM concentrations (Yu et al. 2011). The antibiotics affected the Asparagine tRNA synthetase, which suggests that the mechanism of action in *E. histolytica* could be through affecting RNA-associated enzymes.

As compared to echinomycin A and tirandamycin A, metronidazole is a more potent inhibitor of tropozoite growth. However, toxic side effects and increasing metronidazole resistance by parasitic microbes (Bendesky et al. 2002; Crowell et al. 2003; Haque et al. 2003; Ali and Nozaki 2007) limit its clinical use. These results suggest that both echinomycin A and tirandamycin A could be pursued as alternative treatments for amoebiasis.

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