

Infection with tungiasis through inter-host movement of adult female sand fleas, *Tunga penetrans*

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Tungiasis is a highly neglected tropical skin disease caused by the parasitic, adult female sand flea, *Tunga penetrans*. More than 80% of tungiasis patients are found in the age group under 15 years, in the elderly population and in people with disabilities. Tungiasis is a public health threat in the most marginalized, resource poor communities of Sub-Saharan Africa, South America, and the Caribbean[1]. Patients struggle to walk, and their sleep is disturbed due to itching and pain. Children avoid going to school and hesitate to play with their friends because walking is painful. Their quality of life is significantly impaired [2] especially when constant re-infection leads to chronic clinical manifestations including desquamation, hyperkeratosis, fissures, ulcers, lymphoedema and loss of nails and deformation of toes[1]. Bacterial super-infection is common exacerbating the inflammation and pain[1].

The cause for all this suffering is the unique lifestyle of the adult female sand flea that burrows into the epidermis and once fully embedded after approximately 6-8 hours, starts to grow over a period of 7 days until it reaches the size of a pea. This process is known as neosomy and

serves the development of hundreds of eggs in the flea's expanded abdomen [3]. It is this growth of the parasite that causes the intense inflammation, pain and itching[1].

Little entomological research has been implemented to date to fully understand the factors supporting the life cycle of *Tunga penetrans* as well as those supporting the distribution of this parasite. The off-host cycle is initiated when eggs are expelled from the gravid female and drop on the ground where under optimal conditions larvae hatch after 3-4 days. The larvae develop in the upper surface layer of loose soil, sand and dust in a similar way than most other species in the flea family (Siphonaptera) [3]. The larval development takes at least 7 days after which the larvae pupate and it takes another 7-9 days before adult fleas emerge to infect the next host [3].

Several studies in different countries, have identified demographic, behavioral and environmental factors intricately associated with poverty, as a risk for heavy infection such as sleeping in rooms or attending classrooms with soil floors, and not washing feet frequently with soap [4]. *Tunga penetrans* mostly parasitizes the feet, but can also be found on fingers, elbows and backs of patients that are severely restricted in their mobility [5]. This is a clear indicator of the close association between the floor where the off-host stages develop and the host. Most flea species breed close to the resting and sleeping places of their hosts, in sand, soil, dust, dirt, and cracks in floors and *Tunga penetrans* is no exception. This association assures constant re-infection within the living quarters of the host.

Here we report an observation from the field that might help understand how sand fleas and therefore tungiasis expands its distribution in space. All authors experienced once or repeatedly becoming infected by a female sand flea while conducting close observations of embedded fleas, sometimes placing one foot of the patient on their knees. During these times investigators wore closed shoes and were situated on cleanly swept, unbroken concrete floors where the flea, which penetrated the foot of the investigator, was unlikely to have developed. We frequently experienced during these close observations, live adult fleas running across the skin of the patient's feet. These included both, males who were observed to mate with the embedded females, and females looking for a suitable site to penetrate (see supplementary

video S1). During a medical exam of a severely infected individual, one of the authors collected more than a dozen free-living, male and female sand fleas from the skin.

From our observations, we suggest that people do not only get infected from areas where the off-host stages develop, but also through inter-host movement of adult female sand fleas when in close contact with severely infected individuals. Conditions of crowding might support this movement. Crowded classrooms for example, might contribute to the spatial distribution of this disease within a village. Children sitting in close proximity to a heavily infected child might get infected and spread the disease to new households. In rural African schools it is not unusual, for up to 4 pupils to share a desk, and up to 100 children being confined for several hours in a classroom.

Based on the observations reported here, we propose further research into the behavioral ecology of the sand flea, *Tunga penetrans*, with special emphasis on host finding and selection cues and the time the free-living female parasite takes on the host skin before burrowing into the epidermis. Furthermore, establishing the frequency of interhost movements, the role of crowded conditions and the role of this in disease distribution would provide important epidemiological insight.

Immediately, we would recommend that public health departments and schools in disease endemic areas take responsibility for treating all infected pupils at regular intervals and thus protect all pupils and potentially prevent the spread of the disease to a wider community. Any such action must be undertaken sensitively to avoid worsening the stigma associated with infection.

Supplementary Material

S1. Video of an adult female *Tunga penetrans* attempting to penetrate the skin. © Marlene Thielecke
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Competing Interests None

Ethical Approval These observations were made during multiple studies all of which received ethical approval from the appropriate review committees in each country.

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