Topographic Distribution of the Sand Flea *Tunga penetrans* in Wistar Rats and Humans in Two Endemic Areas in Brazil

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Abstract. Tungiasis is a zoonosis caused by *Tunga penetrans*. In Brazil, tungiasis is endemic in many resource-poor communities, in which various domestic and sylvatic animals act as reservoirs. Eighty laboratory-raised Wistar rats were exposed to *T. penetrans* in areas of intense transmission: a fishing village and an urban shantytown in Ceará State, northeast Brazil. The topographic distribution of lesions in Wistar rats was compared with the distribution of lesions in humans in the same area. Our results show that the topographic distribution of embedded sand fleas was almost identical in Wistar rats and humans and that lesions were confined to the feet. In humans, 76% of all lesions were located periungually, whereas in Wistar rats, 67% of lesions were located at the distal end of the digits ($P = 0.73$). Both had the majority of lesions at the toes and digits: 70.2% versus 65.7% ($P = 0.79$). The Wistar rat model mirrors human tungiasis in topographic distribution.

INTRODUCTION

Tungiasis, a zoonosis caused by the female sand flea *Tunga penetrans* and related species, affects a broad range of domestic and sylvatic animals.¹ Embedded sand fleas have been found in monkeys,^{2–4} dogs,^{5–7} cats,⁷ pigs,^{4,8} cattle,^{4,7,9} sheep,⁴ goats,¹⁰ sylvatic rodents,¹¹ coatis,⁴ and even armadillos.^{11,12} Although a self-limiting infestation by its nature, tungiasis is a debilitating disease associated with considerable morbidity in humans as well as the animal host.^{13–20} In human tungiasis, more than 97% of all embedded sand fleas are located at the feet.¹⁶ However, at the feet, embedded sand fleas are heterogeneously distributed, with the periungual areas, the heels, and the lateral rim of the foot being predilection sites.¹⁶ Systematic studies on the topographic distribution of sand flea lesions in animals do not exist.

We have previously shown that Wistar rats can be easily infested with *T. penetrans* under laboratory conditions and that animals exposed in natural environments can be used as sentinels to assess local transmission dynamics.^{14,19,21} Additionally, these animals are an ideal model to study the kinetics of immunological host–parasite relationships.²¹ In this study, we investigated whether, in the Wistar rat, the topographic distribution of embedded sand fleas is similar to the distribution in humans.

MATERIAL AND METHODS

The study was performed in Vicente Pinzón II, a resource-poor community (favela) at the outskirts of Fortaleza, the capital of Ceará State, northeast Brazil and Balbino, an impoverished fishing community 60 km south of Fortaleza. The study areas have been described previously in detail.^{17,20,22} The village of Balbino is located on a dune, and houses are situated on rather large compounds (average = 500 m²). Many families keep dogs and cats as pet animals. Tungiasis is hyperendemic in the area, with a prevalence of up to 51% in the dry sea-

son.¹⁷ The favela Vicente Pinzón II is located close to the beach. The area is densely inhabited, and compounds are small. There is no public waste collection, and a lot of garbage litters the area. Many families keep dogs and cats as pet animals (59% in Balbino).²³ Eighty 4-week-old laboratory-raised Wistar rats (weight = 180–200 g) were placed in cages and exposed in groups of four to six at several different locations in the two areas. We selected compounds where at least one member of a household was affected by tungiasis. For a period of 14 days, the cages were kept in shady areas on the ground, and the animals were in direct contact with the soil. The rats received food and water *ad libitum*. Animals were examined every day for the presence of newly embedded sand fleas. The number of sand fleas and the topographic localization of the lesions were noted on a visual documentation form.

During the same period, in 168 infested individuals from the two communities, the exact topographic distribution of sand flea lesions was documented. The patient age ranged from 1 to 66 years.

STATISTICAL ANALYSIS

Data were entered into an Epi-Info database (Version 6.04d; Centers for Disease Control and Prevention, Atlanta, GA) and checked for entry-related errors. The database was exported into SigmaStat (Version 2007; Systat Software GmbH, San José, CA) for analysis. Relative frequencies were compared with the Fisher exact test. Because the variables assessed were not normally distributed, we used the medians as a measure of central tendency.

RESULTS

In total, 59 of 80 (74%) Wistar rats became infested. During the observation period of 14 days, 140 embedded sand fleas were identified in the animals; 61% of the penetrations took place during the first 3 days of exposure. The median number of lesions in the infested animals was two (range = 1–6 lesions), with no difference between the study areas.

In all cases, the penetration was confined to the feet. The topographic distribution of the lesions is detailed in Table 1. The hind legs were nine times more often affected than the

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TABLE 1

Topographic distribution of 140 embedded sand fleas in 59 infested Wistar rats

Anatomical distribution of embedded sand fleas	Study area		
	Urban slum <i>n</i> (%)	Fishing village <i>n</i> (%)	Both study areas <i>n</i> (%)
Anterior part left foot	5 (8.3)	3 (3.8)	8 (5.7)
Anterior part right foot	4 (6.7)	3 (3.8)	7 (5)
Posterior part left foot	22 (36.7)	32 (40.0)	54 (38.5)
Posterior part right foot	29 (48.3)	42 (52.5)	71 (50.7)

front legs (10% versus 90%; $P < 0.01$). There was no difference between the left and right foot or between the number of lesions per animal in the two study areas.

All lesions of the feet were located at the digits or footpad (Table 2). Lesions mainly developed at the distal end of the digit (67%). The number of embedded sand fleas differed between the digits, being lowest in digits 2 and 3. The footpads contained the remaining 34% of lesions.

In 168 infested humans, in total, 2,984 lesions were documented. The median number of lesions was 17 (range = 1–30). There was no difference in the number of lesions between the left and right foot ($P = 0.89$).

As depicted in Table 3, there was no significant difference in the topographic distribution in Wistar rats and humans. In humans, 76% of all lesions were located periungually, whereas in Wistar rats, 67% of all lesions were located at the distal end of the digits ($P = 0.73$). Humans and Wistar rats had the vast majority of lesions at the toes and digits, respectively: 70.2% versus 65.7% ($P = 0.79$). Digit/toe 1 and 5 were more often affected than other digits/toes.

DISCUSSION

The major parasitological characteristics of *T. penetrans* and related species are broad host specificity. Virtually any domestic or sylvatic mammal stepping with its feet or resting for some time on the ground can become infested.^{11,12,18} It is usually assumed that female sand fleas penetrate the epidermis at the site where skin has come into contact with the soil for a protracted period of time. However, inhabitants of endemic areas frequently have observed adult sand fleas running on uncovered body parts such as the legs or the arms.^{16,22} In fact, in humans, penetration can occur at any site of the body, sometimes leading to an uncommon clinical picture not suggestive of tungiasis.^{16,17} However, generally, more than 94% of embedded sand fleas are located at the feet.¹⁶

Whether this clustering also occurs in animals acting as an important reservoir for human infestations has never been

TABLE 2

Topographic distribution of 140 embedded sand fleas at the feet of 59 Wistar rats

Topographic area of rat foot	Study area		
	Urban slum <i>n</i> (%)	Fishing village <i>n</i> (%)	Both study areas <i>n</i> (%)
First digit	10 (16.7)	21 (26.3)	31 (22.4)
Second digit	4 (6.7)	3 (3.8)	7 (5)
Third digit	7 (11.7)	1 (1.3)	8 (5.4)
Fourth digit	6 (10.0)	12 (15.0)	18 (12.9)
Fifth digit	10 (16.7)	18 (22.3)	28 (20)
Foot pad	23 (38.4)	25 (31.3)	48 (34.3)

TABLE 3

Comparison of the topographic distribution of embedded sand fleas in Wistar rats ($N = 140$) and humans ($N = 2,984$)

Topographic area of foot affected	Wistar rats <i>n</i> (%)	Humans <i>n</i> (%)	<i>P</i> value
First digit/toe	31 (22.1)	625 (20.9)	0.82
Second digit/toe	7 (5)	378 (12.7)	0.4
Third digit/toe	8 (5.7)	317 (10.6)	0.54
Fourth digit/toe	18 (12.9)	300 (10.1)	0.71
Fifth digit/toe	28 (20)	476 (16.0)	0.65
Foot pad/sole of foot	48 (34.3)	888 (29.8)	0.76

studied. Anecdotal observations indicate that embedded sand fleas are encountered at topographic sites that never or rarely come into contact with the ground. In cattle, for example, lesions were observed in the perianal area, and in bulls, lesions were observed on the preputium.⁹ In dogs, lesions have been observed at the muzzle; in pigs, lesions have been observed at the snout, and in boars, lesions have been observed at the scrotum.^{7–9} In this study, we investigated if the anatomic distribution of embedded sand fleas in Wistar rats is similar to the distribution in humans.

In fact, all 140 embedded sand fleas observed in 59 naturally infested Wistar rats were located at the feet of the animals. The hind legs were nine times more often affected than front legs. This finding may be explained by the fact that rats keep hind legs on the ground at all times, whereas front legs are lifted (e.g., when the animal is not moving). The particular topographic distribution shares similarities with findings in children living in an endemic area. In children aged 0–4 years, the hands were disproportionately more often affected compared with older children who rarely place their hands on the ground (Buckendahl J, unpublished observation).

Of all *T. penetrans* lesions in Wistar rats, 34% occurred at the footpads. In humans living in the same endemic area, the sole of the foot, a topographic area that corresponds to the footpad in rats, was affected in 30% of the cases. Similarly, in rural Nigeria, 34% of all lesions were encountered at the sole of the foot.²⁴ The first and fifth digits/toes were more often affected the other three digits/toes (Table 3). This finding is surprising, because digit five has the smallest surface compared with the other digits/toes. The lateral position and the exposed surface seem to play a role in its higher risk of infestation.

Taken together, the topographic distribution of sand flea lesions in Wistar rats is almost identical to the distribution in humans. Hence, the Wistar rat model mirrors human tungiasis in this respect. We need additional investigations to validate our findings.

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