

Toxoplasma gondii

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Toxoplasma gondii is a parasite that can cause serious disease in humans, especially in pregnant women.

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1. Introduction

Toxoplasma gondii is the most widespread zoonotic protozoan parasite that has a wide range of warm-blooded hosts at its disposal. Sexual replication of *T. gondii* occurs in the intestine of felines, which are the end host of the protozoan parasite. Humans and most animals are considered intermediate hosts because they harbor tissue cysts containing tachyzoa [1]. It is estimated that one-third of the human population is infected with *T. gondii* [1]. Prenatal infections can lead to severe problems and even death [2], whereas postnatal toxoplasmosis, although rare, can cause eye and behavioral problems [3][4][5][6][7][8]. Humans can become infected in several ways: 1. by ingesting oocysts shed by cats, 2. by consuming food or water contaminated with oocysts, or 3. by consuming undercooked meat containing the encysted parasite [9][10][11][12]. Up to 50% of human toxoplasmosis cases are foodborne. Consumption of undercooked meat products containing *T. gondii* tissue cysts is the main risk factor for infection [13][14][15]. Although meat from domestic pigs is of greater concern [15], consumption of wild boar (*Sus scrofa*) meat has gained popularity [16][17]. This is mainly due to the successful spread of the species in the environment [17][18] and an increase in recreational hunting [16][17]. Wild boar, as omnivores, can contract toxoplasmosis by consuming food or water contaminated with sporulated oocysts or by ingesting infected tissues from other intermediate hosts [19]. The global seroprevalence of *T. gondii* in wild boar is estimated at 23%, with the highest seroprevalence being 26% and 32% in Europe and North America, respectively [17]. This high prevalence of toxoplasmosis makes wild boar a suitable biological model for the dynamic assessment of *T. gondii* in the environment where the wild boar population is constantly present [17][20]. Currently, there is no surveillance program for *T. gondii*-infected meat intended for human consumption [17], although the European Food Safety Authority (EFSA) has identified *T. gondii* as a relevant biological hazard that needs to be addressed [21]. The significant increase in the Central European wild boar population in recent years means an even greater risk of human and animal exposure to *T. gondii* [22].

2. Samples

Wild boar serum samples ($n = 353$) were collected in 2016 and 2017 from apparently healthy, free-ranging animals throughout Slovenia as part of the national surveillance program for brucellosis and African swine fever. Game wardens and hunters were asked to submit samples from animals shot during the regular annual harvest. Hunters were also instructed on procedures before sample collection and were provided with field sample kits. Shortly after death, blood samples were collected from the jugular vein or the heart. The samples were transported to the veterinary faculty at the University of Ljubljana, where the serum was obtained and stored at -20°C until testing for Toxoplasma antibodies. Only animals whose harvest location, sex, age, and weight were recorded by the hunters were used for this study. The animals' weights were determined by using a scale. The age of the animals was determined by tooth eruption, replacement, and wear.

3. Antibodies against *T. gondii*

Antibodies against *T. gondii* were detected in 220 of 353 (62%; CI 0.57–0.68) wild boar over a 2-year period. The univariate analysis showed seroprevalence in male and female wild boar of 63% and 61%, respectively, and the difference was not statistically significant ($p = 0.781$) (Table 1). However, seroprevalence was significantly associated with age ($p = 0.003$), weight ($p = 0.002$) and harvest location ($p = 0.043$) (Table 1). The results show an increase in prevalence from 51% in animals less than 1 year old to 83% in adult wild boar of 2–3 years old. Prevalence was 36% in animals weighing less than 20 kg, whereas it was over 70% in animals weighing more than 60 kg (Table 1). Weight and age had, adjusting for gender and region, similar predictive ability, AUC = 0.665 and 0.641 (AUC = area under the curve), respectively (Table

2). When adjusted for gender and region, 1–2-year-old animals had higher odds to be positive for *T.gondii* than 0–1-year-old animals (OR = 1.69, 95% CI: 1.02–2.77). Similarly, 2–3-year-old animals had higher odds than 1–2-year-old animals (OR = 2.66, 95% CI: 1.03–6.85), whereas the oldest group of animals (more than 3 years old) had a smaller, but not statistically significant, odds than animals aged 2–3 years (OR = 0.50, 95% CI: 0.15–1.63).

Table 1. Seroprevalence of *T. gondii* in wild boar based on sex, age, weight, and region.

Wild Boar	Tested Animals (%)	<i>T. gondii</i> Positive (%)	<i>p</i> *
Gender			0.781
male	209 (59)	132 (63)	
female	144 (41)	88 (61)	
Age (years)			0.003
0–1	125 (35)	64 (51)	
1–2	162 (46)	105 (65)	
2–3	35 (10)	29 (83)	
>3	31 (9)	22 (71)	
Weight (kg)			0.002
0–20	33 (9)	12 (36)	
20–40	137 (39)	79 (58)	
40–60	99 (28)	66 (67)	
60–80	55 (16)	42 (76)	
>80	29 (8)	21 (72)	
Region			0.043
1 obalno kraska	2 (1)	2 (100)	
2 goriska	20 (6)	13 (65)	
3 primorsko notranjska	43 (12)	18 (42)	
4 osrednjeslovenska	18 (5)	12 (67)	
5 gorenjska	0	0	
6 jugovzhodna slovenija	129 (36)	87 (67)	
7 posavska	30 (8)	21 (70)	
8 zasavska	12 (3)	8 (67)	
9 savinjska	20 (6)	8 (40)	
10 podravska	55 (16)	33 (60)	
11 pomurska	24 (7)	18 (75)	
12 koroska	0	0	

Data are frequencies (%), * *p*-value from a chi-squared test with continuity correction.

Table 2. Risk factors for the prevalence of *T. gondii* in wild boar. The results are OR (95% confidence intervals) and *p*-values.

Wild Boar	Model 1 (AUC = 0.664)	Model 2 (AUC = 0.665)	Model 3 (AUC = 0.641)
Gender	<i>p</i> = 0.963	<i>p</i> = 0.911	<i>p</i> = 0.915
male vs. female	1.01 (0.63–1.61)	1.03 (0.65–1.63)	0.98 (0.61–1.54)
Age (years)	<i>p</i> = 0.301		<i>p</i> = 0.004

Wild Boar	Model 1 (AUC = 0.664)	Model 2 (AUC = 0.665)	Model 3 (AUC = 0.641)
1–2 vs. 0–1	1.24 (0.70–2.19) [<i>p</i> = 0.454]	/	1.69 (1.02–2.77) [<i>p</i> = 0.038]
2–3 vs. 1–2	2.19 (0.78–6.09) [<i>p</i> = 0.132]	/	2.66 (1.03–6.85) [<i>p</i> = 0.042]
>3 vs. 2–3	0.47 (0.13–1.65) [<i>p</i> = 0.238]	/	0.5 (0.15–1.63) [<i>p</i> = 0.249]
Weight (kg)	<i>p</i> = 0.094	<i>p</i> = 0.001	
20–40 vs. 0–20	2.54 (1.11–5.84) [<i>p</i> = 0.028]	2.74 (1.21–6.2) [<i>p</i> = 0.015]	/
40–60 vs. 20–40	1.22 (0.66–2.23) [<i>p</i> = 0.52]	1.42 (0.81–2.48) [<i>p</i> = 0.216]	/
60–80 vs. 40–60	1.41 (0.61–3.24) [<i>p</i> = 0.417]	1.58 (0.73–3.38) [<i>p</i> = 0.238]	/
>80 vs. 60–80	0.76 (0.24–2.36) [<i>p</i> = 0.64]	0.8 (0.28–2.25) [<i>p</i> = 0.666]	/

After adjusting for gender and region, animals weighing 20–40 kg had higher odds than animals weighing 0–20 kg (OR = 2.74, 95% CI: 1.21–6.20), whereas higher weight was no longer significantly associated with further increasing the odds for being *T.gondii*-positive (OR = 1.42, 95% CI: 0.81–2.48, OR = 1.58, 95% CI: 0.73–3.37 and OR = 0.80, 95% CI: 0.28–2.25 for 40–60 kg vs. 20–40 kg, 60–80 kg vs. 40–60 kg and over 80 kg vs. 60–80 kg, respectively). Due to high collinearity between age and weight (*p* < 0.001), both effects were, adjusting for gender and region, not significant when age and weight were simultaneously included in the model (*p* = 0.301 and 0.095 for age and weight, respectively) (**Figure 1**).

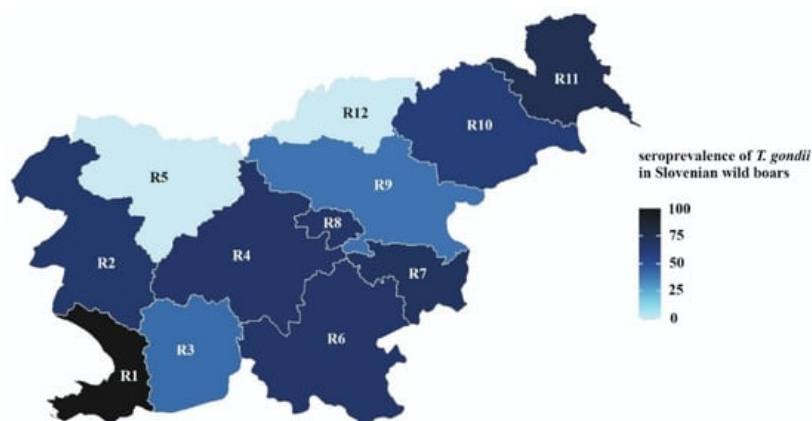


Figure 1. Seroprevalence of *T. gondii* in Slovenian wild boar (%). Regions (R): R1—obalno kraska, R2—goriska, R3—primorsko notranjska, R4—osrednjeslovenska, R5—gorenjska, R6—jugovzhodna Slovenija, R7—posavska, R8—zasavska, R9—savinjska, R10—podravska, R11—pomurska, R12—koroska.

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